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Volume 71 Number 1

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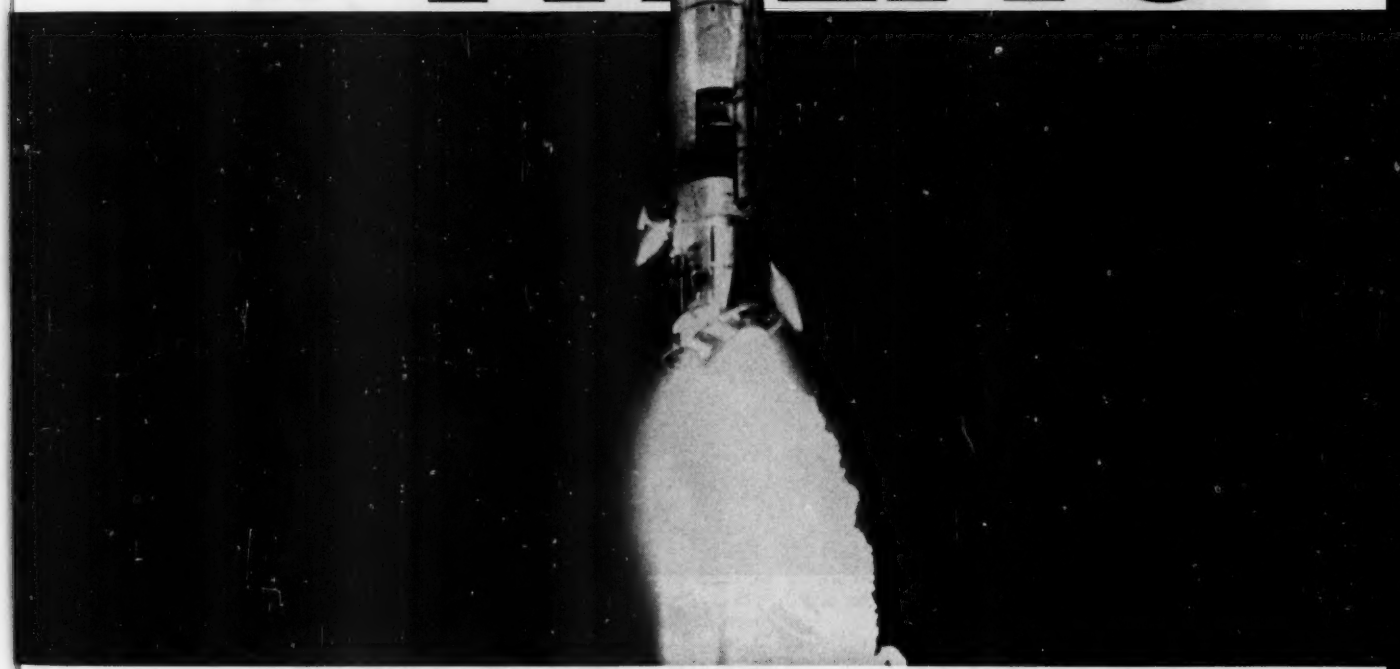

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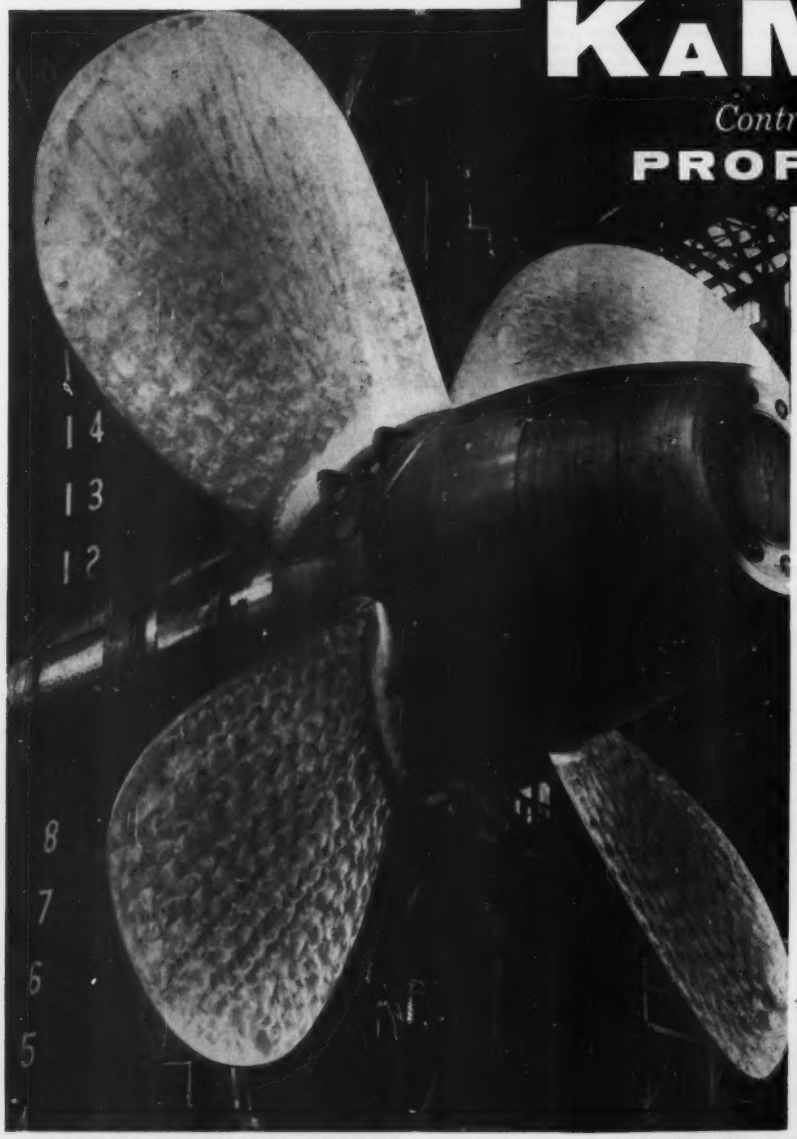

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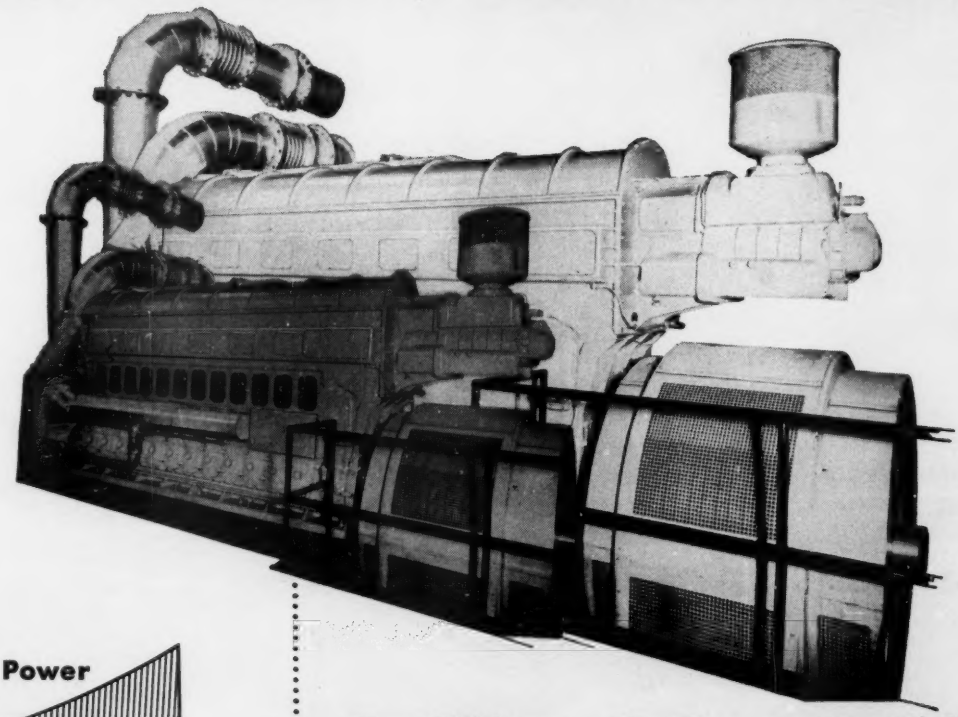
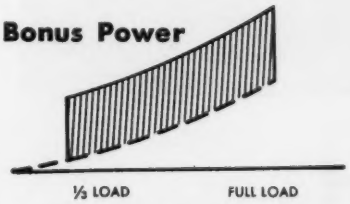


Bonus Power



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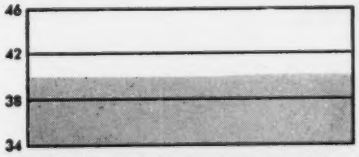

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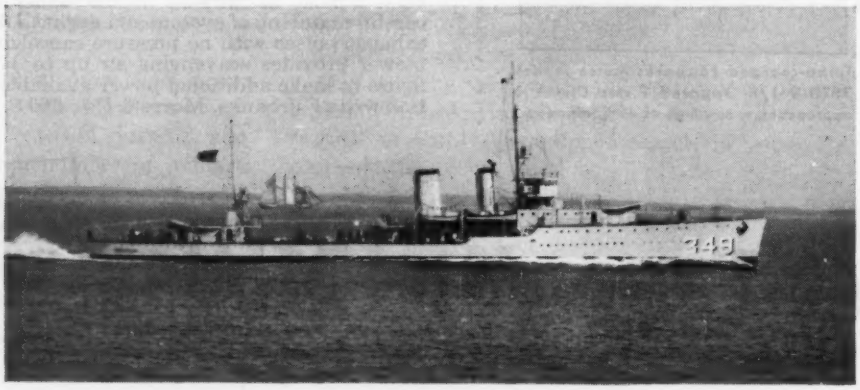

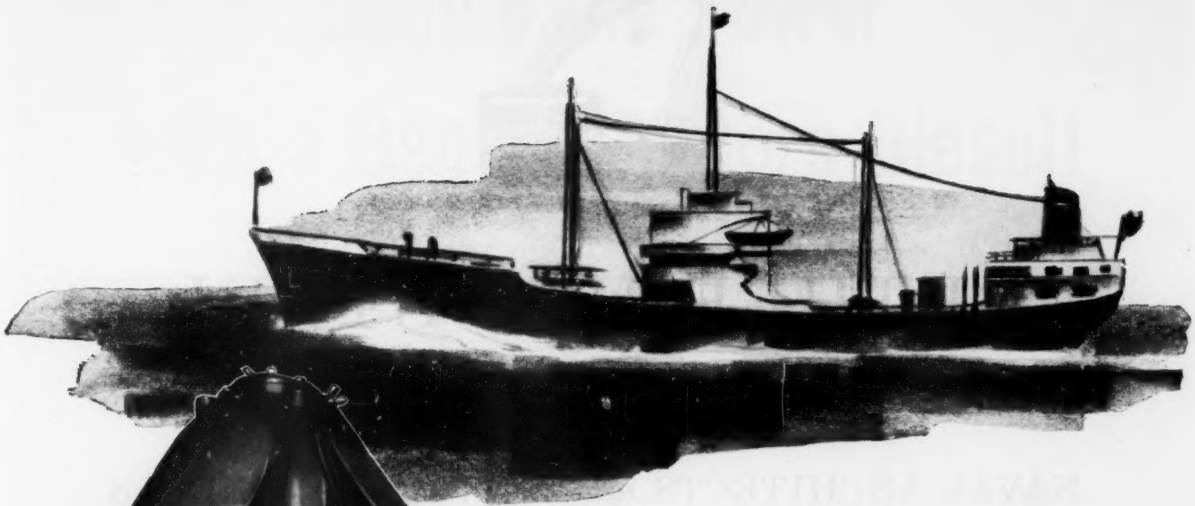

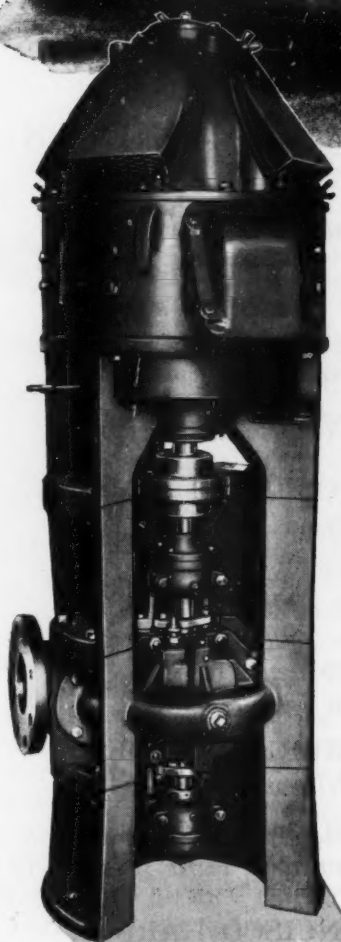

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7–58

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Red Star Vice-President Robert W. Sanders says, "The DEVON far excels our highest expectations both as to power developed and flexibility. This tug is required to go into every creek from New York to the Cape Cod Canal, some of which are difficult for a 100-foot tug to navigate. But, with her General Motors engine and Wichita controlled-slip clutch, the DEVON can work in these confined waters without difficulty." Mr. Sanders also reports the increased power has proved its worth on "open water" tows of oil and chemicals to Philadelphia.

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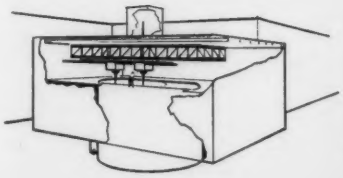

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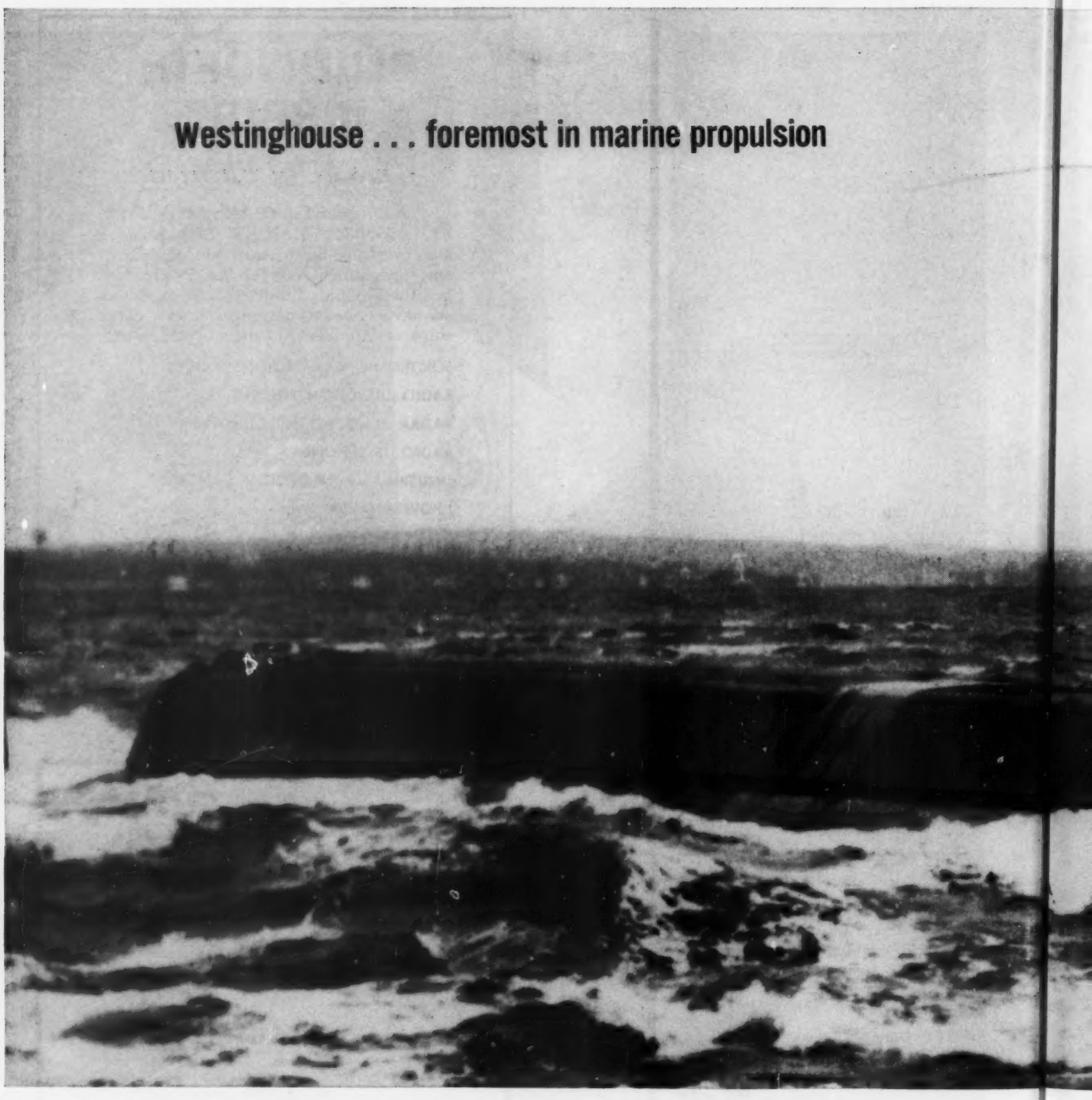

PROVEN DEPENDABILITY OF

Here is part of the report given by Commander J. F. Calvert, skipper of the nuclear submarine, SKATE (SSN 578), after a 203 hour underwater Atlantic crossing. ". . . It just purrs along, on and on, day after day. It's almost unbelievable, but nothing went wrong. I didn't hear anything from my engineer the whole way over . . ."

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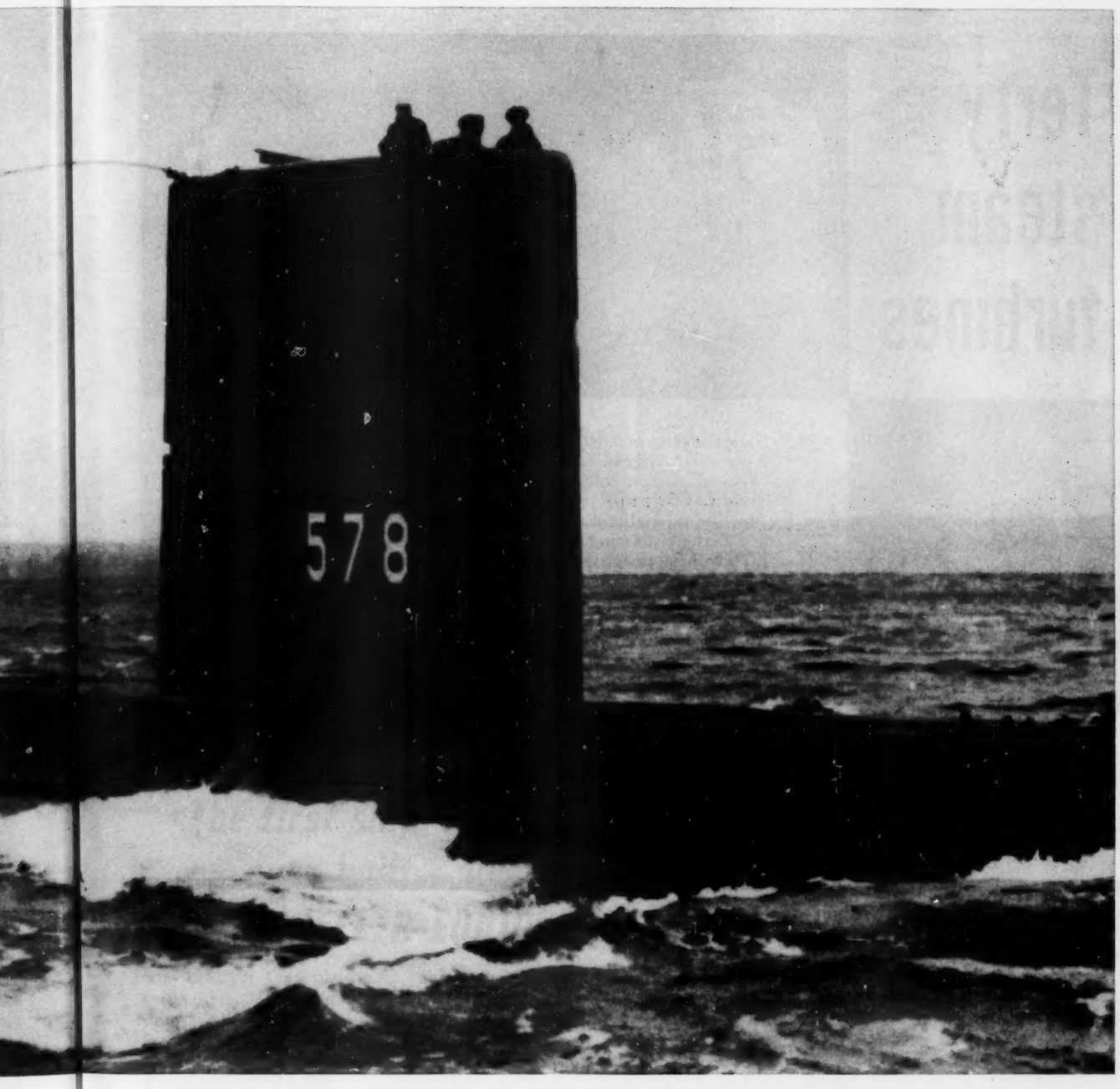
Take advantage of the years of Westinghouse research and experience in the design and construction of marine equipment for your next ship construction project.

The SKATE'S engine room equipment includes Westinghouse-built propulsion turbines and gearing, condensers, turbine-generators, switchgear,



THE PROPULSION PLANT

group control and nuclear instrumentation and control. The nuclear reactor was designed and developed by Westinghouse under direction of and in technical cooperation with the Naval Reactors Branch, Atomic Energy Commission.

Westinghouse Electric Corporation, 3 Gateway Center, P.O. Box 868, Pittsburgh 30, Pennsylvania.

J-92015

The SKATE'S pressurized water reactor is similar in principle to that of the NAUTILUS, but incorporates many new concepts and advances in reactor design. Official U. S. Navy photograph.

YOU CAN BE SURE... IF IT'S

Westinghouse

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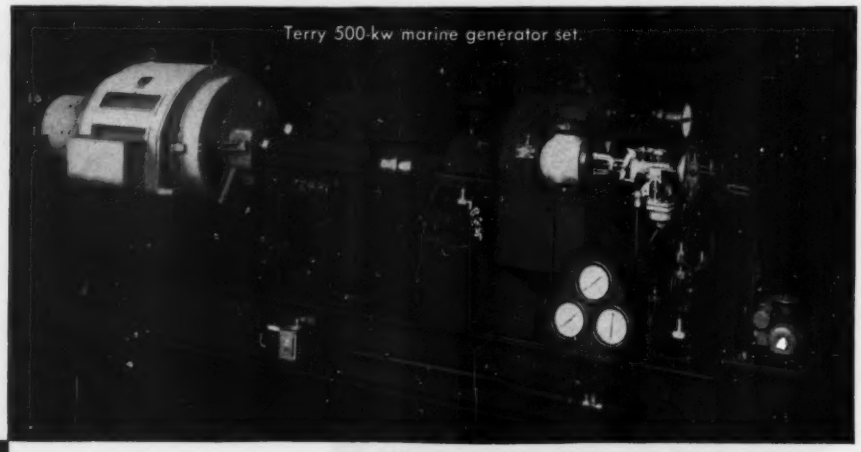
Terry steam turbines


Terry 500-kw marine generator set.

Terry solid-wheel turbine with upper half of casing removed.

Dependable, compact, efficient . . . Terry marine turbines are specially designed for driving generators, boiler-feed pumps, fuel-oil pumps, compressors, etc., aboard ship. They are the result of over fifty years of experience in designing equipment for commercial and naval vessels.

Turbines ranging from 5 to 3000 hp are built in the Terry solid-wheel design as well as in axial-flow, single-stage and multi-stage types.

Complete details of turbines for any application will be gladly furnished.

THE TERRY STEAM TURBINE CO.
TERRY SQUARE, HARTFORD 1, CONN.

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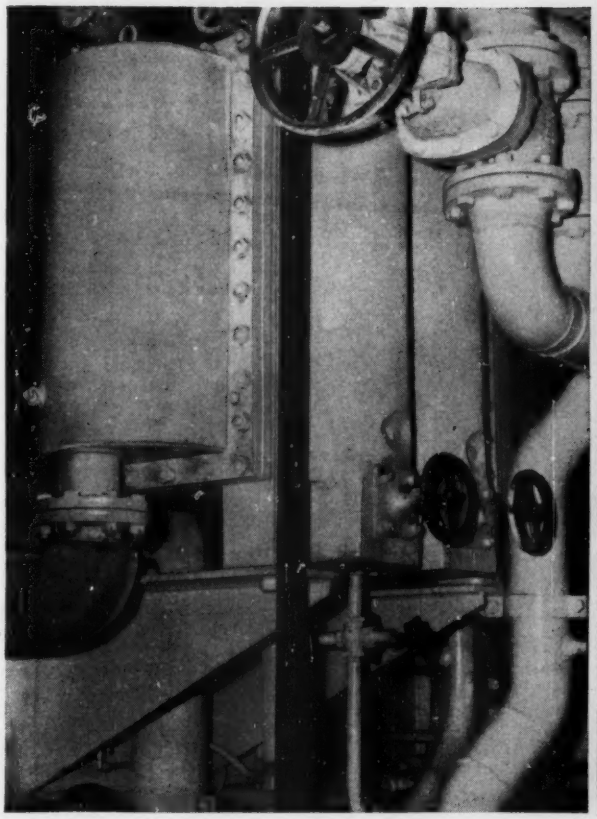
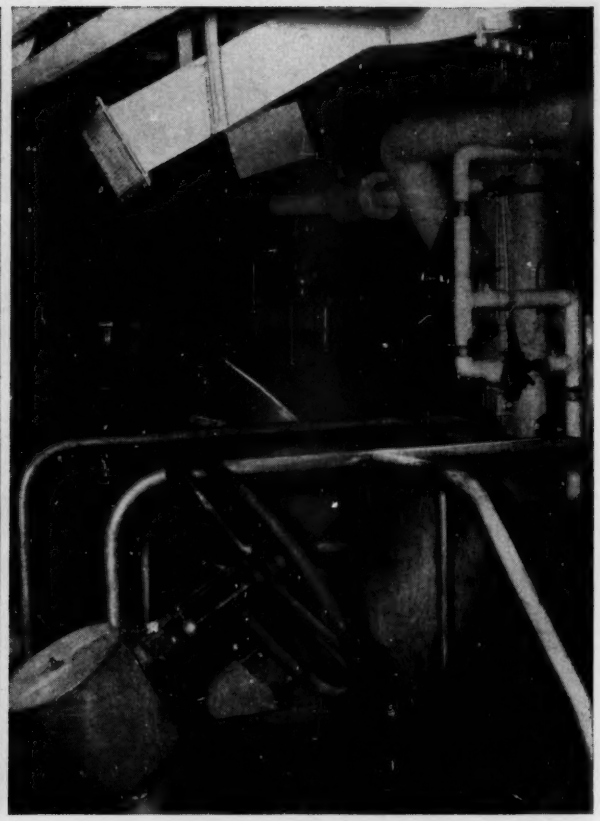
KINGSBURY THRUST and JOURNAL BEARINGS

THE NAVY'S CHOICE FOR 40 YEARS

Kingsbury Machine Works, Inc. KINGSBURY **Frankford, Philadelphia 24, Pa.**



Compact design and ready accessibility of C. H. Wheeler Twin-Element, Two-Stage "Tubejet" Air Ejectors contribute to efficient machinery arrangement in the U.S.N.S. Comet.



Two C. H. Wheeler Condensers, hung from 6000 hp GE turbines, were designed to turbine requirements. They give minimum condensate depression and effective steam distribution.

The first ship of its kind ever built—and she's WHEELER-EQUIPPED!

The U.S.N.S. *Comet* is the first ship ever built specifically for roll/on, roll/off cargo service. As such, she's unique—but in one respect the *Comet* has much in common with other large vessels, new and old.

She's equipped with C. H. Wheeler Main Condensers and "Tubejet"® Air Ejectors. Each Condenser has 4,865 sq. ft. of area, is of the Single Pass type, and is designed for scoop injection. Construction is of ¾" O.D., 18 B.W.G., 90-10 copper-nickel tubes and tube plates. The "Tubejet" Air Ejectors on the *Comet* are of the twin-element, two-stage design with surface inter-after condenser and gland steam condensing sections.

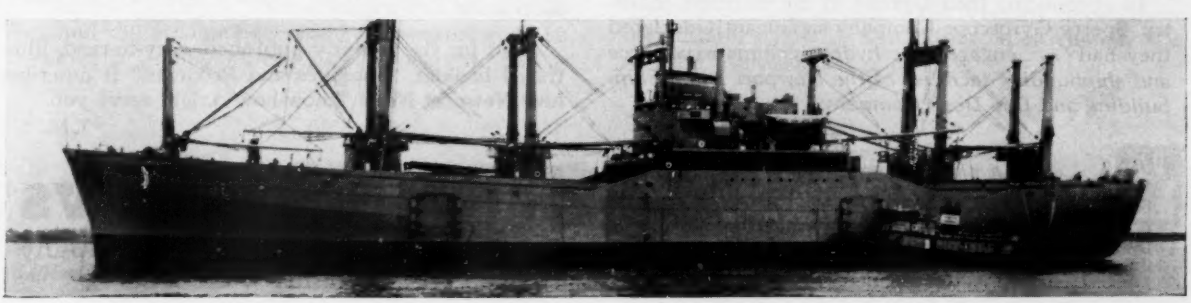
Next time you're planning on marine condensers check on C. H. Wheeler's lightweight, compact design. Find out about "Tubejet" Steam Jet Air Ejectors, with integral piping and valving, too.

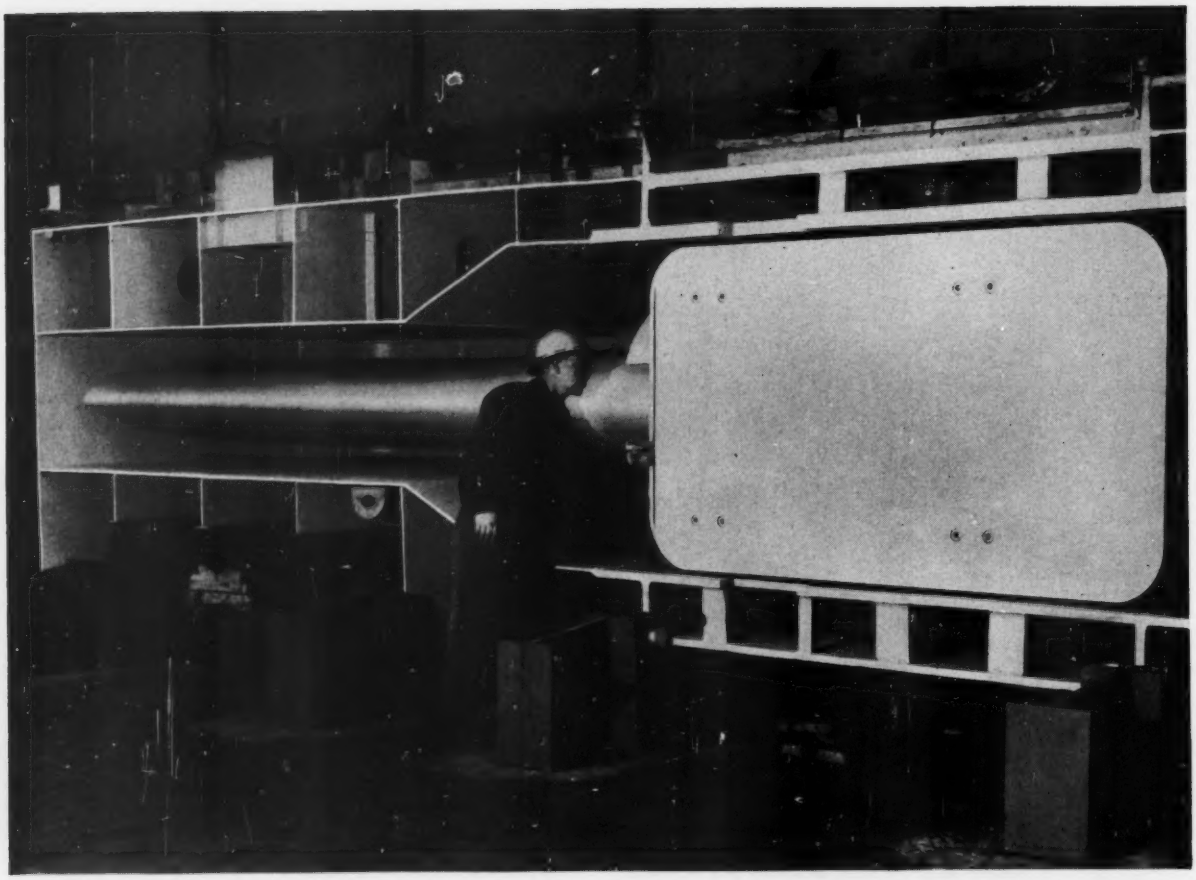
Marine Division

C. H. Wheeler Mfg. Co.

19TH & LEHIGH AVENUE
PHILADELPHIA 32, PA.

Marine Condensers, Ejectors, Pumps & Auxiliary Machinery • Steam Condensers • Vacuum Equipment • Centrifugal, Axial & Mixed Flow Pumps • Nuclear Products





Fin, Fin Box and Machinery Unit, produced by Newport News for the "Gyrofin" ship stabilizer developed by Sperry Gyroscope Company, occupies but little space . . . a recess of 8 feet in the hull. This unit is part of two sets built by Newport News for installation on the Matson Lines' *Mariposa* and *Monterey*. Newport News recently completed a similar set for the U. S. Navy.

Newport News puts "know-how" into fins designed to cut ship's roll as much as 90%

The "fin" shown here is less than 15 feet long. Yet—two of them can stop the roll of a 20-thousand-ton ship!

They're part of the amazing new Sperry Gyrofin* Ship Stabilizer. Together, these "fins" deliver up to 6000 foot-tons of "lift" or anti-rolling movement. They keep a 20-thousand-ton ship smooth, steady and on its course. Result: new high levels of sustained speeds . . . increased propulsion efficiency and freedom from boarding seas in rough weather.

In announcing their Gyrofin to the maritime industry, Sperry Gyroscope Company significantly declared they had "*. . . engaged the hydro-dynamic experience and shipbuilding facilities of the Newport News Shipbuilding and Dry Dock Company.*"

Newport News tested hydro-dynamic scale models to determine Gyrofin system design characteristics. And to detect possible stress concentration points in the fin itself, with typical thoroughness Newport News made stress analyses of individual components in the plant's Hydraulic Laboratory.

Comprehensive Newport News "know-how". . . including decades of metal working experience . . . goes into actual building of the stabilizers. Into castings, weldments, steel fabrication and extensive machine shop work.

Send for the recently published, easy-to-read, illustrated booklet, "Facilities and Products." It describes how Newport News "know-how" might serve you.

*T.M.

Engineers. . . Desirable positions available at Newport News for Designers and Engineers in many categories. Address inquiries to Employment Manager.

Newport News
Shipbuilding and Dry Dock Company
Newport News, Virginia

NETHERLANDS' GREATEST LINER IS LAUNCHED

Holland-America Line's new flagship Rotterdam is outfitted with the most modern equipment on the seas

The $28,000,000 liner, Rotterdam, sponsored by Queen Juliana, slid down the ways on September 13. When she goes into service—in October 1959—she will join the ranks of the world's great transatlantic liners. The 37,000 gross-ton vessel will be the largest passenger ship in the Dutch merchant marine and the sixth largest using the Port of New York.

The new flagship is 758 feet long, with a beam of 93 feet, and will accommodate 1,400 passengers and 750 crewmen in totally air-conditioned quarters. She is equipped with the very latest navigating and operational devices, including automatic stabilizing fins. Among many other features, the Rotterdam boasts two swimming pools, a 600-seat auditorium-theatre, eleven elevators and four escalators. Her exterior appearance is notable for the absence of conventional funnels.

The Rotterdam is powered by four boilers of the Combustion Engineering V2M Vertical Superheater design built by N. V. Koninklijke Maatschappij "De Schelde," Vlissingen, Holland.

COMBUSTION ENGINEERING

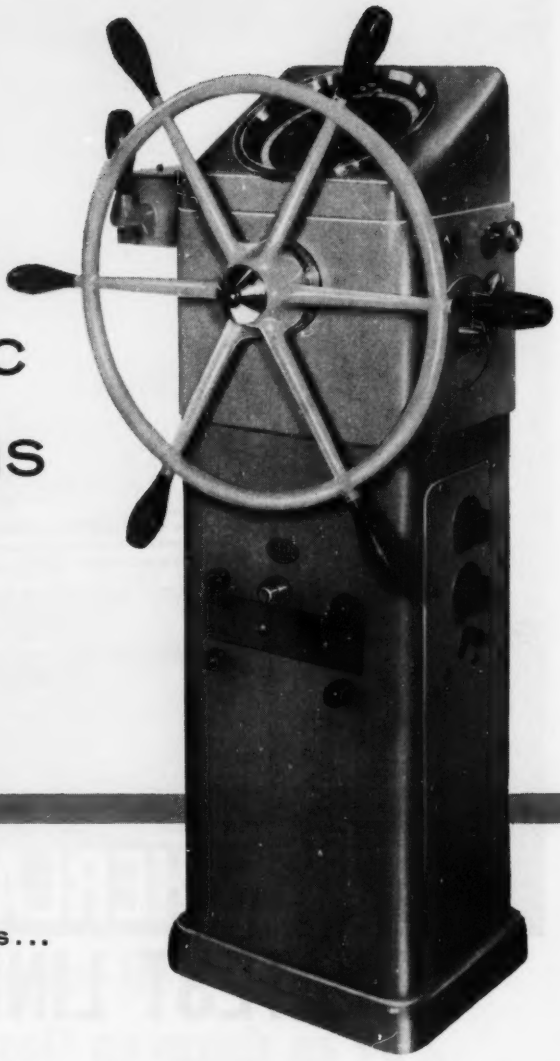
Combustion Engineering Building, 200 Madison Avenue, New York 16, N. Y.

C-E

C-186

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

Sperry offers Electro-Hydraulic Steering Systems adaptable to any type vessel



Standard units give choice of system arrangement to meet individual requirements... telemotor eliminated

For safe, trouble-free steering, Sperry has a wide variety of modern electro-hydraulic control systems. All eliminate the need for a hand telemotoring system and feature instantaneous change-over to all-electric standby systems.

Your requirements may dictate the choice of automatic, full follow-up hand electric or non-follow-up hand electric control working through main and auxiliary circuits. The diagrams on the next page point up the flexibility inherent in all Sperry Steering Control Systems.

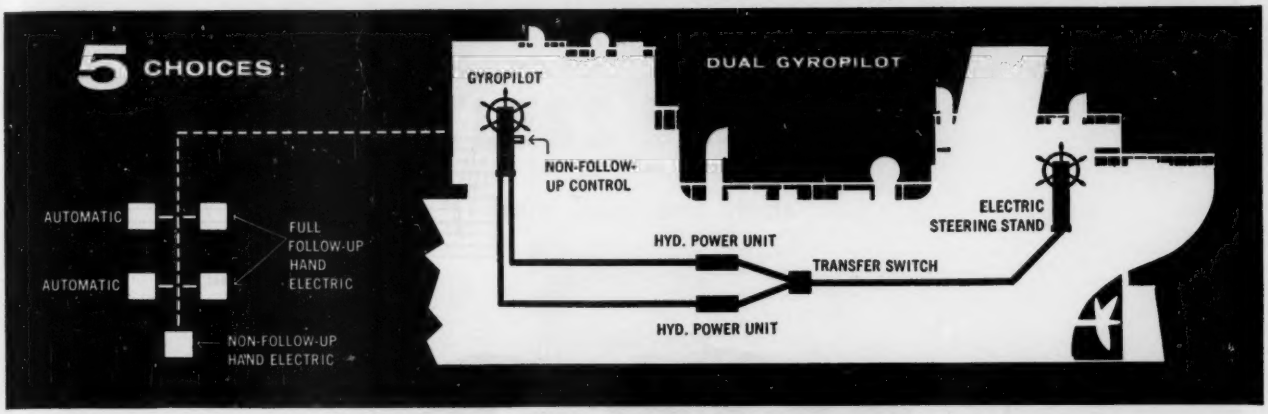
A Sperry Electric Steering Stand at the After Steering Station (conforming to Coast Guard Ruling 57.25-47) eliminates rotary shafting to the steering engine room – thus is free from mechanical binding and friction. This watertight stand speeds transfer of control from Wheelhouse to After Steering Station and reduces installation and maintenance costs.

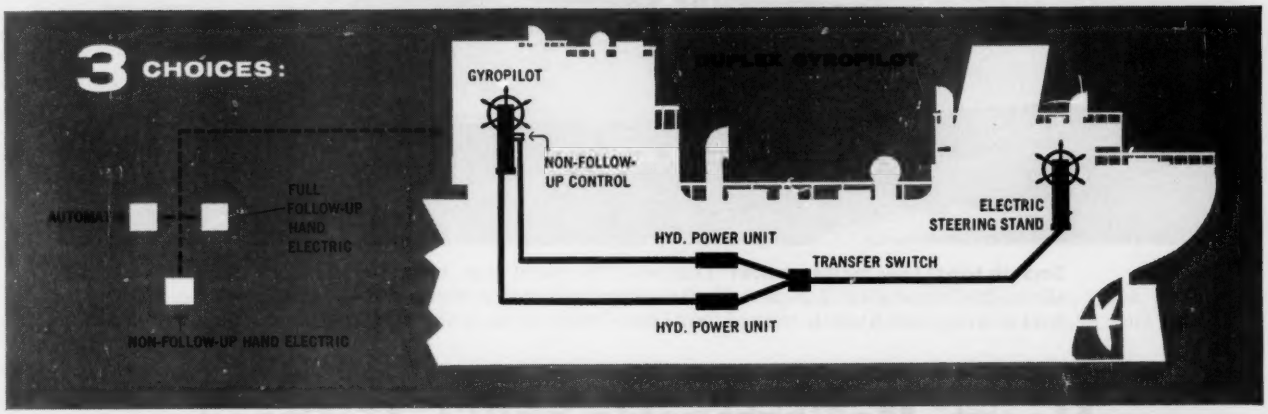
If you're interested in a proven, flexible steering system that combines positive hydraulic actuation with dependable electrical control —and eliminates the telemotor—call our nearest district office.

Dual Gyropilot* Steering Stand combines two independent systems in a single stand. This permits use of either of two automatic controls, either of two full follow-up hand electric controls and a standby non-follow-up hand electric control. *T.M.

SPERRY

SPERRY PIEDMONT COMPANY,
CHARLOTTESVILLE, VIRGINIA
DIVISION OF SPERRY RAND CORPORATION
Address all inquiries: *Charlottesville, Virginia or Sperry Gyroscope offices in Brooklyn Cleveland · New Orleans · Los Angeles Seattle · San Francisco*


5 CHOICES:
AUTOMATIC
AUTOMATIC
FULL FOLLOW-UP HAND ELECTRIC
NON-FOLLOW-UP HAND ELECTRIC
DUAL GYROPILOT
GYROPILOT
NON-FOLLOW-UP CONTROL
ELECTRIC STEERING STAND
HYD. POWER UNIT
TRANSFER SWITCH
HYD. POWER UNIT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NON-FOLLOW-UP HAND ELECTRIC
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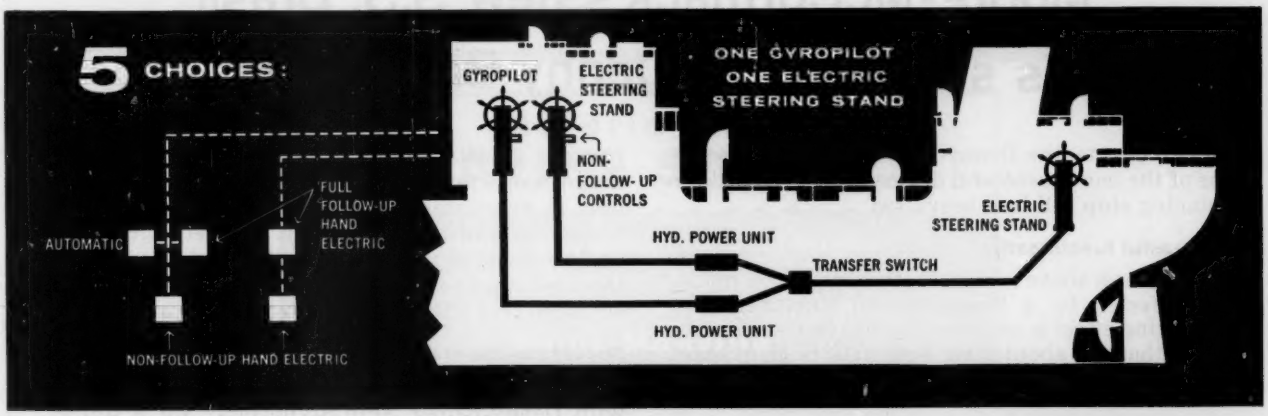
ELECTRIC STEERING STAND
HYD. POWER UNIT
TRANSFER SWITCH
HYD. POWER UNIT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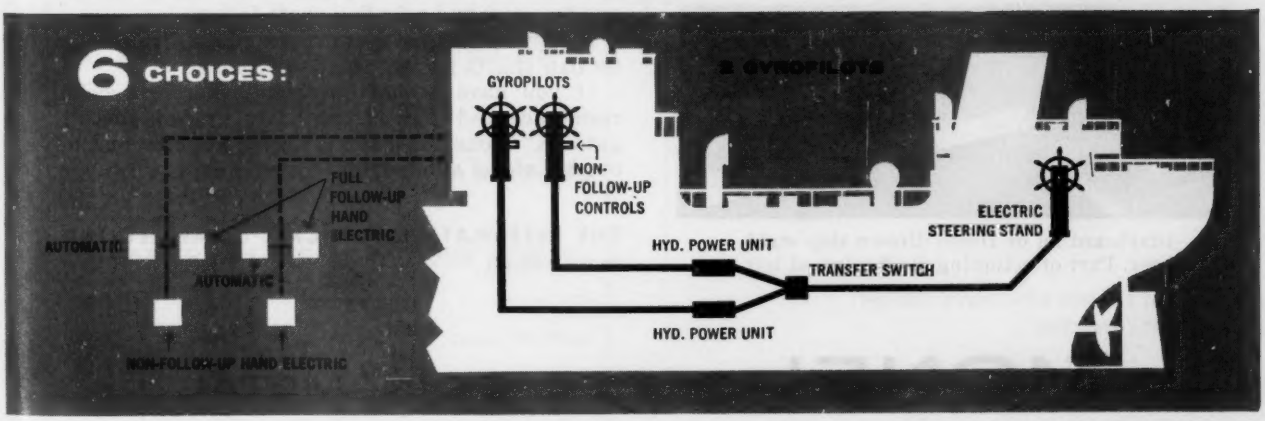
HYD. POWER UNIT
TRANSFER SWITCH
HYD. POWER UNIT


6 CHOICES:
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AUTOMATIC
FULL FOLLOW-UP HAND ELECTRIC
NON-FOLLOW-UP HAND ELECTRIC
GYROPILOTS
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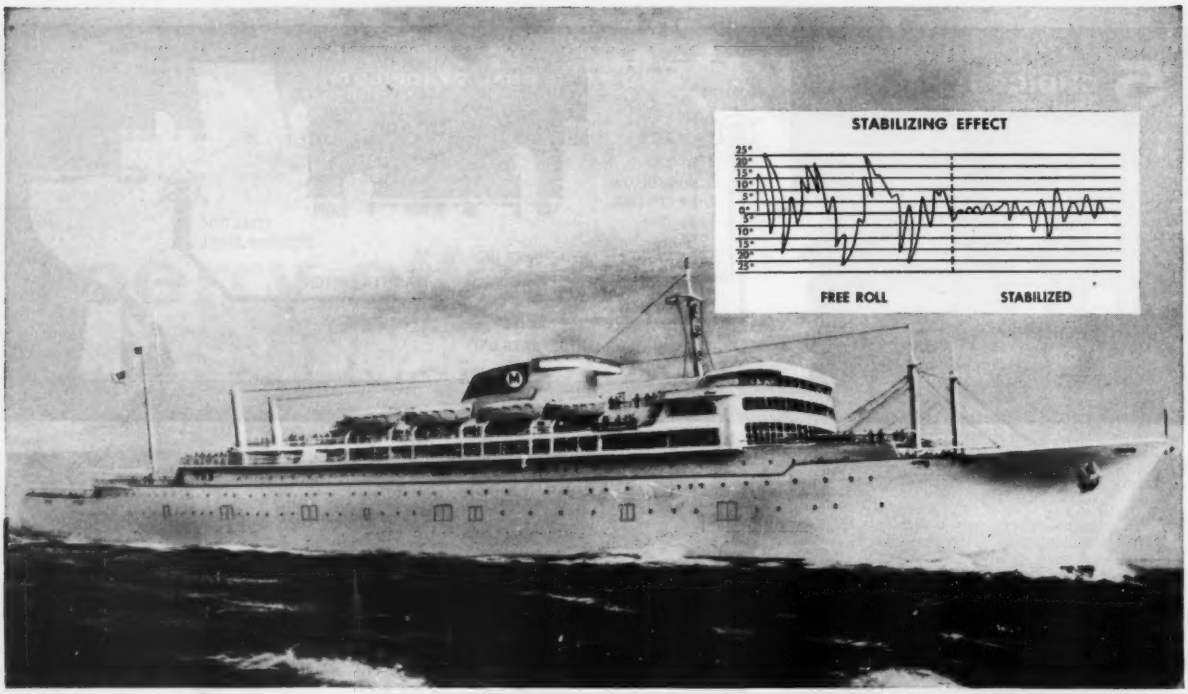
ELECTRIC STEERING STAND
HYD. POWER UNIT
TRANSFER SWITCH
HYD. POWER UNIT



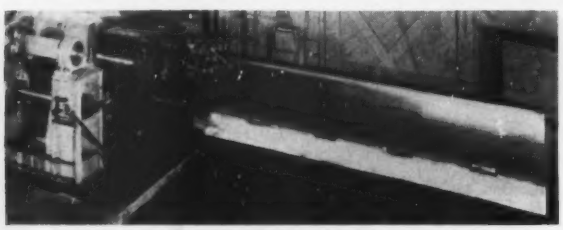
Smooth trips! Low maintenance! That was the word that went to designers of Moore-McCormack's *S.S. Brasil.* So she's stabilized with a Denny-Brown unit. Inco Nickel Alloys are used in critical locations — such as the stabilizer tail flap shaft.

Moore-McCormack's new S.S. Brasil is stabilized by Denny-Brown unit

On two counts, the Denny-Brown ship stabilizer is one of the most successful devices yet developed for reducing ship roll in a heavy sea.

Successful functionally

The graph above is an actual record of roll reduction effected by a Denny-Brown stabilizer. The stabilizing effect is produced by two fins—or hydrofoils—that tilt about their long axes to counteract wave motion. The tail flaps increase the fins' effectiveness. Shafts joining the flaps to main fins undergo severe torque and abrasion . . . are lubricated only by sea water. For this reason, Denny-Brown makes them of hard, tough "K" Monel* age-hardenable nickel-copper alloy. "K" Monel alloy gives them resistance to corrosion and wear plus the high strength this critical application demands.



Starboard fin of Denny-Brown ship stabilizer. Part of actuating mechanism at left.

Successful maintenance-wise

Here and abroad 181 ships have been equipped with Denny-Brown Ship Stabilizers. Not a single one has ever had a fin flap shaft failure.

In the new Moore-McCormack ships, "K" Monel fin flap shafts are standard equipment.

If you have a shaft problem where corrosion resistance and high strength are needed, investigate "K" Monel. You can get complete information on this nickel alloy simply by writing us.

*Registered trademark

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street — New York 5, N. Y.

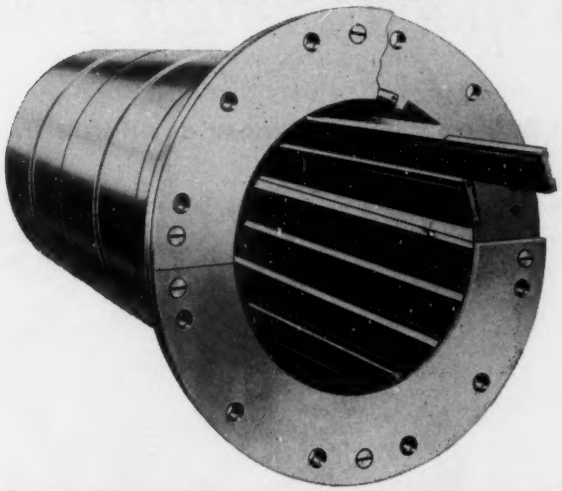
INCO

MONEL THE SEAGOIN'* METAL

CUTLESS BEARINGS

for

Stern Tubes and Struts



Soft rubber bearing surface—efficiently lubricated by water—this bearing far outlasts all hard surface types, protects propeller shafts, reduces vibration. More than pays for itself in extra wear alone. Saves you time, trouble, and upkeep expense.

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Akron, Ohio

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Materials for MARINE SERVICE

Incombustible Joiner Materials • Acoustical Materials
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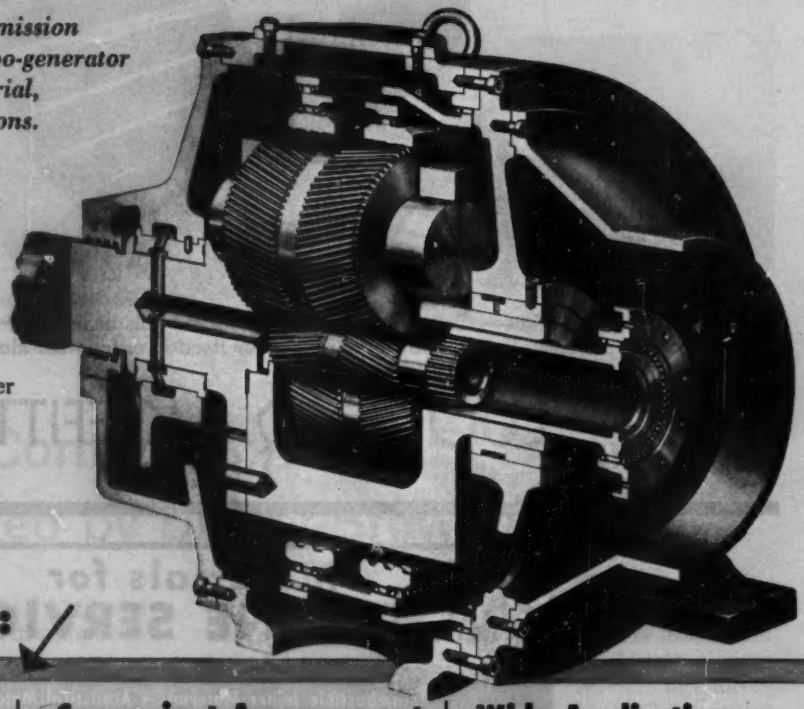
PLANETARY GEAR

...for high speeds...high horsepower

Proved in hundreds of installations abroad totalling over 3,000,000 horsepower—now available in America!

For all high torque power transmission applications such as pump turbo-generator and compressor drives in industrial, municipal and marine installations.

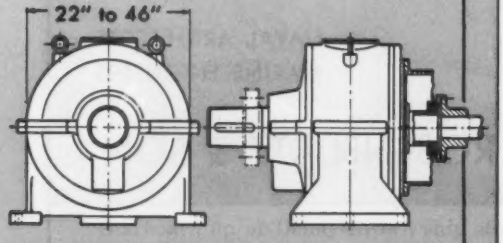
This cutaway view of the De Laval-Stoeckicht Planetary Gear shows how it provides flexibility for proper load distribution throughout the gear members. The thoroughly proved and tested design is completely reliable in transmitting high horsepower for high speed applications. • Highest efficiencies (98% or higher)...no high speed bearings...less friction losses.



Check These Advantages:

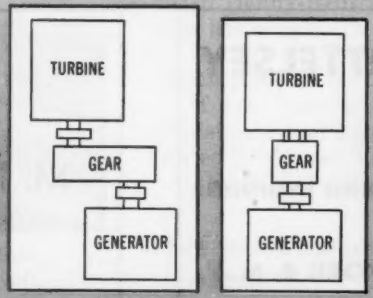
Small Size—Light Weight

Compact—low weight per hp. Sizes range from 22" to 46" in diameter, depending on horsepower requirements. Example: 5000 hp planetary unit weighs 1700 lbs. against 6000 lbs. for conventional gear.



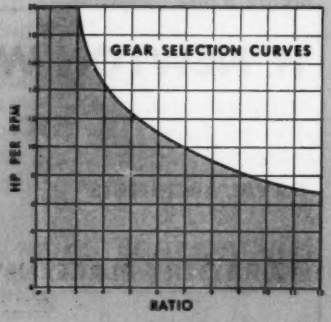
Convenient Arrangement

Co-axial or "in-line" arrangement of gear members takes up far less space than parallel axis gears of equivalent horsepower rating.



Wide Application

Capacity range shown in shaded area on chart below. For other applications, contact your De Laval Sales Engineer.



For further details, write for Bulletin 2400.

DE LAVAL *Steam Turbine Company*

Nottingham Way, Trenton 2, New Jersey

USS PAUL REVERE RIDES PROUDLY INTO SERVICE!

TODD-CONVERTED FROM THE DIAMOND MARINER

Presenting Uncle Sam's largest, fastest attack transport . . . August 30, 1958 climaxed 2 years of planning, engineering and stem to stern conversion, when the Navy took delivery of the USS PAUL REVERE at Todd Shipyards, Los Angeles Division. This advanced design prototype gives 3-way versatility . . . for troop landings by LCM and helicopter, as a 3-battalion command ship, and as a small hospital ship.

From helicopter elevator and 60-ton booms for LCMs and tanks to classified features worked out by Naval Research and Todd engineers, here's efficiency in action. This highly experienced, resourceful service is a trademark of TODD on every U. S. coast.

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For more than 50 years, repairers, converters and builders of ships for all the world. ALSO INDUSTRIAL WORK – ALL PHASES.

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Selecting alloys for rolled tube sheets and baffles

Tube sheets and baffles are available from The American Brass Company in a wide variety of shapes, sizes and alloys to meet the problems of corrosion, pressure, and temperature encountered in condensers and heat exchangers.

The following Anaconda alloys are those most widely used for tube sheets and baffle plates.

Leaded Muntz Metal-274 has good strength, stiffness and elasticity. It machines well and is the most commonly used tube-sheet metal. Leaded Muntz Metal hot rolls easily and can be manufactured in very large sizes. Many of the other tube-sheet alloys are superior to Leaded Muntz Metal in corrosion resistance and are used in preference to it for that reason. However, tube sheets are necessarily so thick that a long time elapses before they are affected by corrosion to the extent that their strength or usefulness is impaired.

Naval Brass–450 is an alloy of the same general type as Leaded Muntz Metal but includes approximately 0.75% tin in its composition. The tin content increases the alloy's resistance to corrosion, and makes it preferable to Leaded Muntz Metal, especially at higher than normal working temperatures.

Arsenical Admiralty–439 is resistant to dezincification corrosion and can be used where its higher resistance to corrosion is required, especially in process equipment.

Ambraloy-917 is available for use where strength and corrosion resistance superior to Naval Brass and Admiralty Metal are desired, as in oil-cooler tube sheets.

Cupro Nickel, 10%-755 and Cupro Nickel, 30%-702 are used extensively with tubes of similar composition in marine condensers and in process heat exchange equipment.

Baffle and Support Plates for use in oil refinery equipment are most often of Leaded Muntz Metal and Yellow Brass. For more severe applications Admiralty, Naval Brass, Cupro Nickel, Copper, or Everdur® are often used.

Rolled Plates Superior. Anaconda sheets, plates, and circles are produced by the rolling process. They are commercially flat, accurate in dimensions, and free from the surface imperfections and porosity often prevalent in cast plates.

Standard Sizes. The American Brass Company makes plates for condenser tube sheets of copper and several copper alloys in rectangular sizes up to 156 inches in width and weights up to 15,000 pounds for any shape that can be cut from such sheet. The maximum standard limits for circles are 160 inches in diameter and 11,000 pounds in weight. Half circles can be produced up to 13,000 pounds in weight.

Special jobs. When specifications call for extremely large plates or special alloys for special applications, The American Brass Company will cooperate in the solution of such problems. For further information on Anaconda Condenser Tubes or Tube Sheets write: The American Brass Co., Waterbury 20, Conn.

6875B

ANACONDA®

Tubes & Plates for Condensers & Heat Exchangers made by The American Brass Company

A full-sized metal fabrication plant is being built to operate in an atmosphere of nearly pure argon. Metals which react with atmospheric gases under normal fabrication conditions, such as columbium, tantalum, molybdenum and tungsten, will be processed in the plant being built for the Bureau of Aeronautics by the Universal-Cyclops Steel Corporation. Technicians working in the plant will wear "space suits," specially designed suits, to which hoses will be connected for supplying air and exhausting carbon dioxide. Locks will be provided for ingress and egress of personnel and materials. The atmosphere of the plant is expected to be held to 99.995% pure argon.

—from MECHANICAL ENGINEERING
January, 1959

THE 1959 ANNUAL BANQUET

of

The American Society of Naval Engineers

will be held at

HOTEL STATLER-HILTON

WASHINGTON, D. C.

on

Friday, 1 May 1959

Notices with application forms soon will be mailed to all members.

REAR ADMIRAL WILLIAM A. DOLAN, JR., U. S. NAVY

PRESIDENT FOR 1959

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Journal of the AMERICAN SOCIETY of NAVAL ENGINEERS, Inc.

VOLUME 71 FEBRUARY, 1959 NUMBER 1

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NAVAL ENGINEERING

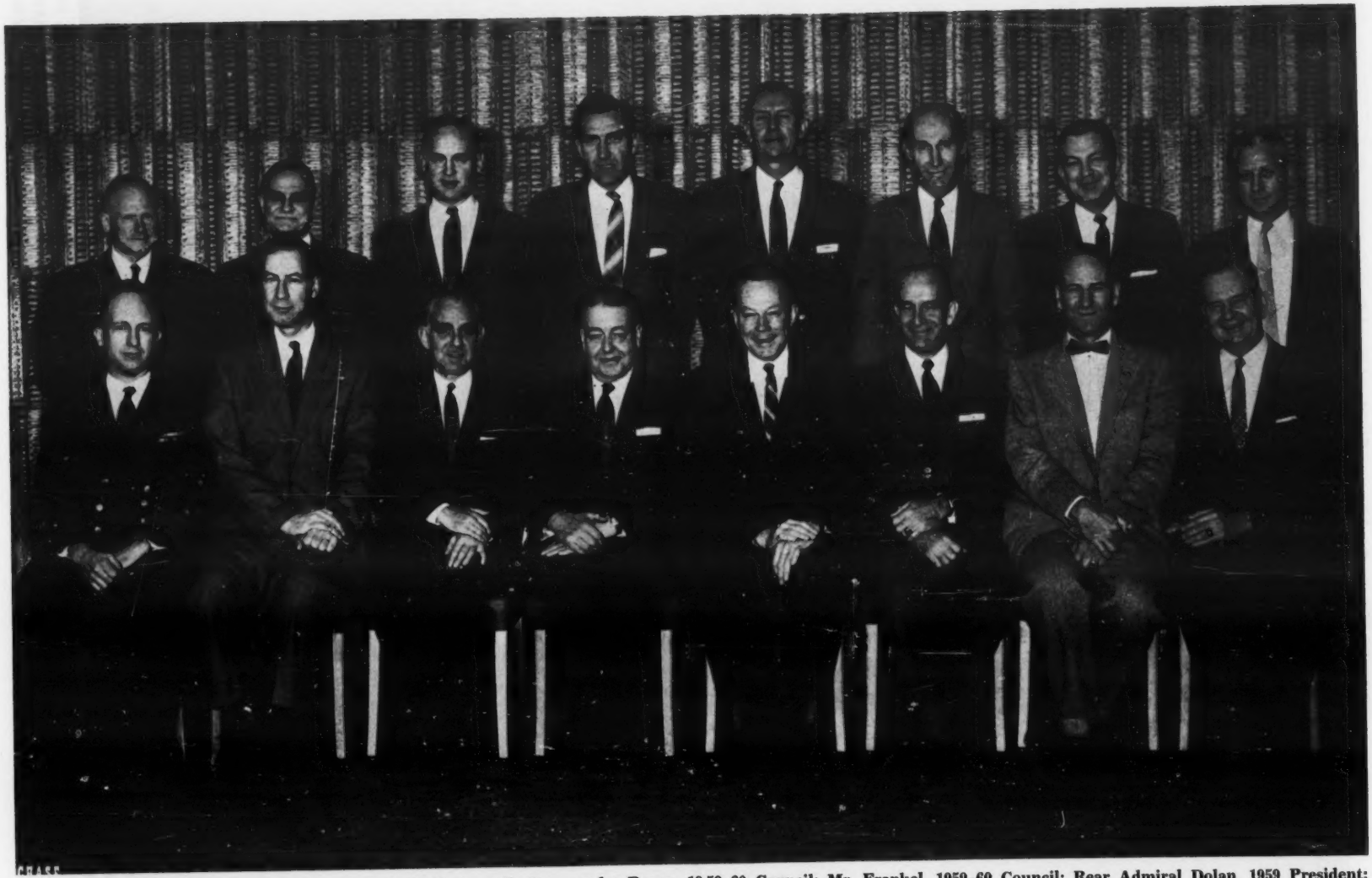
Definition: NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintenance of naval ships and their installed equipment.

SECRETARY'S NOTES

1958 Elections

For another year the Society membership have chosen those in whom it has placed responsibility for Society affairs. Following a custom of several years standing, the results of the election were presented, by the Chairman of the Ballot Counting Committee, Mr. David B. McAulay, to the Council at a dinner meeting which was attended by the successful candidates as guests of the 1958 Council.

At this meeting the outgoing President, Rear Admiral Leroy V. Honsinger, U.S. Navy, passed the presidential reins to the Society's choice for 1959, Rear Admiral William A. Dolan, Jr., U.S. Navy; and the newly elected Council members took their seats vice the members whose terms had been completed.



Seated: Left to right: Captain Brown, 1958, 59-60 Council; Commander Burpo, 1959-60 Council; Mr. Frankel, 1959-60 Council; Rear Admiral Dolan, 1959 President; Rear Admiral Honsinger, 1958 President; Rear Admiral Thiele, 1958-9 Council; Captain Bacheller, 1959-60 Council; Captain Monk 1958-9 Council. Standings Left to right: Mr. McAulay, Chairman Ballot Committee; Captain Hamilton, Sec.-Treas; Captain Madden, Assistant Sec.-Treas.; Lieutenant Commander Redmon, 1958-59 Council; Captain Wright, 1957-58 Council; Captain Adair, 1958-59 Council; Mr. Armstrong, 1957-58 Council; Captain Hartman, 1957-58 Council.

The changes in the Council resulting from the election were:

Captain Edgar H. Bacheller, U.S. Navy, succeeded Captain E. A. Wright, U.S. Navy, as a regular Naval Member;

Commander Robert S. Burpo, U.S. Naval Reserve, succeeded Captain Joseph A. Hartman, USNR, as a Naval Reserve Member; and

Mr. Gilbert S. Frankel succeeded Mr. John B. Armstrong as a Civilian Member.

Captain J. A. Brown, U.S. Navy, a Regular Naval Member and Captain J. E. Hamilton, USN, Retired, Secretary-Treasurer, were reelected.

The composition of the Council for 1959 is as shown above.

Those attending the Joint Council meeting, at which only Mr. Hugh E. Carlton was missing, are shown in the photograph on page 4.

Society Budget

The Secretary submitted a preliminary report of 1958 financial operations to the 1958 Council. This report showed that the net gain for the year was slightly better than that predicted when the year's Budget was originally set up. The actual gain was $954.61 compared to the expectation of $307.50. Admittedly this is a very modest figure but the aims of the Council to reverse the trend of operating at a loss was accomplished. The formal statement of accounts has been prepared and audited but this was not done early enough to permit publication in this issue.

The final 1958 statement shows a net loss in the net worth of the Society in spite of the cash gain for the year's operations. This is entirely a paper loss and does not indicate any loss in real assets. It was brought about by a wholesale clearing from the books of an accumulation of Accounts Receivable whose collection has been deemed to be impossible. The full audited statement will be published in the May issue of the JOURNAL.

ASNE Staff

The Council has approved continuance for 1959 of those who were employed during the latter part of 1958. Captain R. B. Madden, fortunately for the Secretary-Treasurer and for the Society, will continue as Assistant Secretary-Treasurer. Miss Ruth M. Leonard who, on 1 October 1958 was promoted from bookkeeper to Administrative Assistant continues in that position. Mrs. Twila Ellis will continue as general assistant to Miss Leonard.

Society Offices

As an accommodation to a neighboring tenant who must expand, we agreed to move the Society offices from suite 1004 to suite 403 of the Continental Building, 1012 14th St., N.W. The move was made on 15 February 1959 at no cost to the Society. The new offices have the same area as the old.

1959 Banquet

Plans are going forward for the Society Banquet whic, as has been announced, will be held at the Statler Hilton Hotel in Washington on 1 May 1959. Final details sufficient to permit mailing applications have been completed and notices with application forms will reach all members very shortly. In general, arrangements will be the same as in 1958.

Council; Captain Wright, 1957-58 Council; Captain Adair, 1958

THE ASNE AWARD

We have discussed the ASNE award for well over a year. It has been reported and is well known to some that we went through the motion of making the award for 1957 but this was abandoned before finalization when the Council decided that insufficient groundwork had been laid in advance.

An award *will be made* for 1958 unless no nomination supporting adequate merit is received. This can happen, we believe, only if the members are indifferent. Certainly in the year 1958, American citizens have made substantial and remarkable contributions in the field of Naval Engineering whose definition will hereafter ride at the JOURNAL's masthead and is repeated here:

NAVAL ENGINEERING is the art and science applied in the design, construction, operation and maintainance of naval ships and their installed equipment. .....

The award will go to the American citizen who made the most outstanding contribution in the field of Naval Engineering during 1958 **and whose accomplishment is known to the Awards Committee and to the Council.** We have underlined the critical element.

We are writing letters to a large number of officers and officials whose official positions put them where they can observe large segments of the field and we feel that few of them can have failed to note one performance which he considers to be outstanding. We are asking each of these to report this performance whether it be an idea, an invention, a concept, a writing or a physical deed.

By these letters we expect to cover a wide field and we hope that the response will reflect a full appreciation of what the Society intends its award to be.

But that kind of coverage cannot be complete. We are calling on 3400 members of the Society, to each of whom this notice is personally addressed, to report in the form of a citation any truly outstanding contribution which has come to his attention.

We know that many momentous things are being done. We hope that the most valuable of these will be cited to the Council so that the Award Committee will be very hard pressed to make the one outstanding selection.

Please address your citations to the Secretary-Treasurer (ASNE Award)
American Society of Naval Engineers
Suite 403
1012 14th St., N.W.
Washington 5, D.C.

so that it reaches us not later than 15 March 1959. The citation must be thorough enough so that the Committee can make a proper judgement on it.

The success of the ASNE Award will depend to a very great degree on the response by the Membership to this appeal.

CAPTAIN E. A. WRIGHT, USN

THE BUREAU OF SHIPS: A STUDY IN ORGANIZATION

THE AUTHOR

is an Engineering Duty Officer who has served in U.S. Naval Shipyards, the Bureau of Ships, and the U.S. Atlantic and Pacific Fleets. He is presently Commanding Officer and Director of the David Taylor Model Basin. In June 1958, Captain Wright was Chairman of a Board to Implement Reorganization of the Bureau of Ships.

EDITOR'S NOTE: *Proceeds from this paper were contributed to the Navy Relief Society.*

INTRODUCTION

THE roots of all naval engineering in our country are set deeply in the organization of the Bureau of Ships of the Navy Department. It is a highly dynamic and versatile organization. Together with its widespread field activities, *BUSHIPS* is surely one of the most comprehensive and complex technical organizations in the world today. Upon the creativity, productivity and support of the Bureau of Ships depends largely the material readiness of the United States Navy.

Organization is the phenomenon of getting things done through cooperative human endeavor (1). The purpose of this study is to identify the essentials of an organization with the mission of researching, designing, building and maintaining the ships of the U.S. Navy. Part I of the paper will examine the evolution of the Bureau of Ships as an organization, with particular emphasis on the reorganization of June 1958 (2), and related changes in the Navy Department. Part II will discuss organizational principles, and the alignment of the present Bureau of Ships organization with these principles. Emphasis will be placed on those fundamentals of "cooperative human endeavor" that are relevant to the organization of the Bureau of Ships, rather than on detailed description of functions and procedures as found in administrative manuals.

Evolution of the organization of the Bureau of Ships over almost 20 years and through national emergencies of all degrees has developed a mature organizational philosophy and doctrine. In a time of widespread subservience to large organizations and to group behavior (3), the Bureau of Ships has retained in considerable measure individual expressiveness and creativeness. Engineering and scientific specialization has been cultivated functionally and applied objectively to make possible a technical revolution in ship design and building (4). Communication and leadership, the true essentials of any sound organization, are largely through ideas and attitude and example rather than through directives. The Bureau of Ships emphasizes economy of operation, recognizing that perfection is reached in organization, not when nothing else can be added, but when nothing else can be taken away. The Bureau is a widely extroverted organization, both because naval engineering depends on the industrial collaboration of the nation, and because decision-making in government is a plural activity (5).

Technical Service to the Naval Service is, above all, the purpose of the Bureau of Ships, and every facet of internal organization depends upon this external responsibility. In turn, organization is a prerequisite to teamwork. Secretary of the Navy,

John L. Sullivan, writing a decade ago in terms prophetic of the present, said: "The vitality of the Navy and its real strength is found today as always in the men who build, man and operate its fleets and its Shore Establishment and who manage and direct its destiny from the control post of the Navy Department. Neither the will to do nor the ability to perform today is sufficient, however, to develop the application of this strength adequately to discharge the myriad responsibilities imposed on the Navy by world conditions. A flexible, sound organization is essential for that purpose. Of equal importance is that knowledge and understanding of the organization be firm in the minds of its personnel, and that the individual's place in the scheme of things be fixed and identified" (6).

PART I. ORGANIZATIONAL EVOLUTION 1798-1958

Heredity and environment are the master influences in organizations as in the people who man them. In fact, a study of organization is largely a study of people, how they work best together, how they communicate and respond, what motivates them to seek the objectives of the organization, what social drives surround them, and how they accept and apply delegated authority in coordination with each other.

Such a study naturally begins with history and with the evolution of the Bureau of Ships up through 1958. Genes of many years back are clearly distinguishable in the present organization, and some of them will be needed in the future as long as the function of Ships, regardless of organizational position, is important to the Department of Defense. A look at the past provides an appreciation and understanding of the present organizational environment, and perspective for the evolution which will inevitably continue.

The full story of the Bureau of Ships and its Engineering Duty officers has been covered by Paulin (7), Robert (8), ASNE (9), Albion (10), Johnson (11), and others (12) (13), and particularly thoroughly by Madden (14) together with a complete bibliography. Therefore this account will touch briskly on only those matters of intimate concern to a study in organization.

EARLY BUREAUS

The organizational concept of a chief technical advisor for ships to the Secretary of the Navy began with the creation of the Navy Department on 3 May 1798. Benjamin Stoddert, our first Secretary, vested the basic function of the present Chief of the Bureau of Ships in Joshua Humphreys, and designated him Principal Naval Constructor of the United States.

The first reorganization of the Navy Department came as an aftermath to the War of 1812. On 7 February 1815, a Board of Navy Commissioners was established, reporting to the Secretary of the Navy. This Board was responsible primarily for matters of materiel, including construction, maintenance and supply, and so the functional area of ships passed from individual to collective organizational responsibility.

In the Fall of 1841, Secretary of the Navy Abel P. Upshur advised the Congress that the Navy Department was suffering seriously "by the want of a proper arrangement and distribution of duties" and was "in truth, not organized at all" (7). In hearings on the Reorganization Bill which followed, two important amendments were introduced by the House of Representatives; one united the proposed Bureau of Equipment with the proposed Bureau of Construction and Repair, and the other vested the power of appointing Bureau Chiefs in the President and Senate instead of the Secretary of the Navy. The reorganization as amended and signed into law on 31 August 1842 established five bureaus named:

Construction, Equipment and Repair
Navy Yards and Docks
Provisions and Clothing
Ordnance and Hydrography
Medicine and Surgery

Several sound organizational principles were exemplified in the birth of the bureau system in the Navy Department:

(a) Individual responsibility of the Bureau Chiefs was substituted for the collective responsibility of the Navy Commissioners; no provision was made for organizing the Bureau Chiefs into boards and vesting them with corporate functions.

(b) Division of labor among the Bureaus was complete, and the whole equalled the sum of five parts.

(c) Delegation of authority by the Secretary of the Navy to his Bureau Chiefs was the legal mechanism used to unify the new organization.

(d) Technical ability was recognized as a prerequisite to technical leadership; the law specified that the Chief of the Bureau of Construction, Equipment and Repair be "a skillful naval constructor."

(e) Implicit in this original bureau organization was the functional concept of a Bureau of Ships; consolidated responsibilities for designing, building, equipping, delivering and repairing ships of the Navy were assigned to the Chief of the Bureau of Construction, Equipment and Repair.

In December 1861, Secretary of the Navy Gideon Wells recommended certain improvements in organization from which the Navy Department was not to recover for over 75 years. The reorganization, which became law on 5 July 1862, replaced the five original bureaus by eight, named:

Construction and Repair
Equipment and Recruiting
Steam Engineering
Navigation

Yards and Docks
Provisions and Clothing
Ordnance
Medicine and Surgery

The undivided responsibility and authority for work on ships, formerly vested in the Bureau of Construction, Equipment and Repair, were fractioned three ways among the Bureau of Steam Engineering, the Bureau of Equipment and Recruiting, and the Bureau of Construction and Repair. In furtherance of the distintegration, the Bureau of Navigation was made the Scientific Bureau of the Navy Department to handle such matters of growing direct technical importance. Here were the grounds for organizational strife which plagued the Navy Department for many years.

It was at this time that the Chiefs of Bureau, who served formerly at the pleasure of the President, began to be appointed for a term of 4 years. This characteristic of a finite term for the Chief is a significant difference between large governmental and private technical organizations.

When in 1883 the Congress began authorizing a systematic building program of steel ships, the parent bureaus of the Bureau of Ships fostered four practices which have become basic to the present organization: (a) the closest collaboration between national industry and the material bureaus, (b) a vigorous and continuing attack on new technical problems, (c) the orderly sharing of naval shipbuilding between private and naval shipyards, and (d) the advanced education of the officers who were to manage the ship design and building bureaus. During this period, the Bureaus of Construction and Repair, Steam Engineering, Ordnance, and Equipment were heavily in the manufacturing business and organization reflected this emphasis.

MERGER ATTEMPTS

As shipbuilding accelerated, the costly consequences of divided organizational responsibility for the production of physical entities became more evident. For example, *Omaha* was commissioned and supposedly ready-for-sea when "it was discovered that, as a result of the Bureaus working independently, her space had been so appropriated that coal room had been left for no more than four days steaming" (7). Organizationally, each bureau might perform its own work perfectly and still not produce a balanced ship.

Corrective attempts began. In 1883, Secretary of the Navy William E. Chandler urged the merger of the Bureau of Construction and Repair and the Bureau of Steam Engineering into a single Bureau of Naval Construction (11). In 1885, Secretary William C. Whitney recommended that the eight bureaus of the Navy Department be reduced to three:

Material and Construction
Personnel
Finance and Accounts

Neither of these proposals found Congressional approval. To effect some improvement in coordination within his Secretarial power, Secretary Benjamin F. Tracy established in 1889 the Board of Construction, composed of the Chiefs of the Bureaus of Construction and Repair, Ordnance, Steam Engineering, Equipment, and Yards and Docks (14).

Secretary John D. Long in 1899 urged consolidation of the three bureaus principally concerned in shipbuilding into a single bureau which he proposed to call the "Bureau of Ships." Such concentration of large powers in the hands of a Chief of the Bureau of Ships was considered dangerous (7). Again in 1905, Secretary Charles J. Bonaparte suggested that the Department be reorganized into four bureaus dealing with:

Men	Armament
Ships	Supplies

These repeated efforts were reflecting real concern over the organizational inefficiency of divided responsibility for work on ships, and were teaching the lesson that it is easier to create than to correct a poor organization.

When Secretary of the Navy Victor H. Metcalf resigned late in 1908, Truman Newberry moved up from Assistant Secretary to take his place. Almost immediately, Secretary Newberry attempted a consolidation of the Bureaus of Construction and Repair, and of Steam Engineering; Chief Constructor W. L. Capps was ordered to additional duty as Chief of the Bureau of Steam Engineering to fill the vacancy that happened to exist at the time. Newberry's plan contemplated abolishing the Bureau of Yards and Docks, and the Bureau of Equipment. One of the three major divisions of the Navy Department would comprise the Bureaus of Ordnance, Steam Engineering, and Construction and Repair under the Board on Construction (11).

When President Taft followed President Roosevelt in March 1909, George von L. Meyer replaced Truman Newberry as Secretary of the Navy. The merger movement was halted abruptly, and Hutch I. Cone was appointed Chief of the Bureau of Steam Engineering. Secretary Meyer did continue to distribute the duties of the Bureau of Equipment to other bureaus, principally Steam Engineering and Construction and Repair, a process which was completed in 1914.

The Meyer Aide System is remembered as the organizational feature of his administration. Five aides were appointed to coordinate:

Operations	Material
Personnel	Inspection

plus a director of Navy Yards. Their position in the organization was between the Secretary of the Navy and the Bureau Chiefs. Decided objections were voiced, and finally the Attorney General declared the system illegal. A highly significant outcome, however, was legislation providing for a Chief of Naval Operations intended to take over the duties

of the Aide for Operations under the Meyer system.

The original House bill made the new Chief of Naval Operations "responsible for the readiness of the Navy for war." The Secretary of the Navy strongly opposed this provision on the grounds that readiness for war was a responsibility shared by the Bureau Chiefs, the Commander-in-Chief, and the Congress (11). As the measure became law on 3 March 1915, the Chief of Naval Operations was "charged with the operations of the Fleet and with the preparation and readiness of plans for its use in war." For many years, questions of policy and administrative procedures arose in the Navy Department because of loose specification of the key organizational responsibilities of the Chief of Naval Operations. It was the beginning, however, of the present coordination which CNO exercises over the material bureaus.

WORLD WAR I ET SEQ

World War I was fought essentially as a bureau organization in the Navy Department. Although the bureau system has appeared loose and cumbersome, it in reality provided the specialized competence so necessary to make and keep the Navy the most technical and progressive of the Services. Chief of Naval Operations, Admiral W. S. Benson expressed this asset when he said, "The fact that the bureaus as now constituted represent the different sections of the general staff, that they have their special appropriations and are responsible for the proper development and operation of the various parts of the Naval Establishment under their cognizance, gives, in my opinion, to the organization of the Navy Department, a distinctive strength and added efficiency, not possible under a so-called general staff organization."

The Bureau of Steam Engineering had been growing in its scope. Cognizance of electrical and machinery components was initiated in 1887 under the Bureau of Navigation, shifted in 1889 to the Bureau of Equipment, and transferred in 1914 to the Bureau of Steam Engineering. Not long after Marconi's historic transmission between Newfoundland and Ireland in 1901, the beginning of the organizational segment now known as Electronics was created, then called the Radio Division of the Bureau of Steam Engineering (12). It was high time by 4 June 1920 that Steam was dropped and the title became Bureau of Engineering.

Technical support of early naval aviation was lodged principally in the Bureaus of Construction and Repair, and of Steam Engineering, and laboratory support in the U.S. Experimental Model Basin. This team working with Glenn Curtiss created the NC-4, the first aircraft to fly the Atlantic. Perhaps more than any other individual, Rear Admiral David W. Taylor, World War I Chief of the Bureau of Construction and Repair, recognized the need for a Bureau of Aeronautics and worked towards its establishment in September 1921 (15). The organization of the Bureau of Aeronautics was formed by bringing together the Aircraft Division of the Bureau of Construction and Repair which had cognizance of stability and structural design, a division in the Bureau of Engineering which had the responsibility for aircraft engines and propellers, and a division of the Office of Naval Operations which had cognizance of operational matters (16).

The Chief of Naval Operations during World War I took an increasing part not only in connection with Fleet operations but also in operations of the Shore Establishment. Commenting on organizational movement in that direction, Assistant Secretary of the Navy Franklin D. Roosevelt said in 1916 during hearings on a bill to extend the authority of the Chief of Naval Operations, "If a general staff is loaded down with the minutia of business it tends to become ineffective. I think that this is perfectly clear doctrine."

From time to time, consideration was given to removing the Bureau Chiefs from access to the Secretary of the Navy by placing them entirely under the Chief of Naval Operations, a situation which Secretary Josephus Daniels likened to elevating the Secretary to the top of the Washington Monument without giving him a telephone (11). In testimony before the Senate Subcommittee on Naval Affairs in May 1920, he analyzed such a proposal in these terms: "It has been suggested by someone that the general staff idea might be painlessly introduced into the Navy Department by simply making each bureau chief an assistant to the Chief of Naval Operations and thus centralizing the directing power while not depriving any semi-automonous bureau of its individual executive authority. . . . No useful purpose can be served by 'simply changing the sign over the door.' Whether it be the bureau system or an elaborated operations' establishment or a simple pure general staff, the work is there to be done and the duties must remain largely the same, and in the last analysis any change would be a change in name only and not in fact. . . ." If a staff system were tried in the Navy, Secretary Daniels asked who would be qualified as super chief. "Nobody except a most expert and finished naval constructor is competent to pass upon the professional work and technical duties of the constructor. Then, in order to get someone able to intelligently supervise his work, such supervisor must necessarily be another officer of the Construction Corps, and thus you have two skillful constructors doing the work of one. Each other chief of bureau in the Navy Department is equally expert and equally efficient and effective in his particular line of work; so that, if for any reason he needs immediate and detailed supervision from anybody other than such general supervision as is now supplied by the Secretary of the Navy, himself, the solution is simple—get a better man to be chief of bureau" (11).

Under the Secretary and Assistant Secretary, the Navy Department organization in the 1930's comprised major subdivisions for the Chief of Naval Operations, Director of Shore Establishments, Budget Officer, Judge Advocate General, eight Bureau Chiefs, and Senior Members of several independent boards such as the General Board, and the Board of Inspection and Survey. Numerically, the Navy Department had grown from a total of 30 employees at the outset of the bureau system in 1842, up to a strength of about 500 officers and 2800 civilians. The Chief of Naval Operations was providing overall professional leadership, and the division of his office called Operations Material, later changed to Fleet Maintenance, was furnishing some guidance to the material bureaus. However, CNO's organizational tasks were largely planning and coordination; emphasis on command and control would not come until later (10). This, then, was the organizational environment in which the Bureau of Ships was finally delivered.

THE BUREAU OF SHIPS AND WORLD WAR II

With an expanding shipbuilding program again emphasizing the acute need for a functional bureau organization for ships, events moved comparatively swiftly:

20 October 1938—Assistant Secretary Edison appointed Coordinator of Shipbuilding.

11 August 1939—Acting Secretary Edison directed a consolidation of the Design Divisions of the Bureaus of Construction and Repair, and of Engineering.

31 August 1939—Secretary Edison appointed a Board, headed by Rear Admiral S. M. Robinson, to consider separate plans proposed by the two Bureaus for this consolidation.

12 September 1939—The Robinson Board pointed out "the potentially difficult situation of a single agency (the consolidated design divisions) reporting to two co-equal but independent superiors" and recommended full consolidation of the two bureaus into "a unified organization whose responsibility is complete ships" (17).

18 September 1939—Secretary Edison merged the two bureaus by delegating his authority as Coordinator of Shipbuilding to the new Chief of the Bureau of Engineering, and the appointment as Assistant Coordinator of Shipbuilding of the new Chief of the Bureau of Construction and Repair; legal responsibilities and appropriations remained separate.

5 October 1939—Organization manual for the consolidated bureaus was approved.

26 February 1940 — Congressional hearings commenced and so did unexpected difficulties (18).

20 June 1940—Establishment of the Bureau of Ships became Public Law; cognizances of certain items were transferred from the Bureaus of Supplies and Accounts, of Ordnance, and of Navigation to the new Bureau of Ships.

Considering the inherent difficulties, structuring of the consolidated organization was a masterpiece. Whereas the Bureau of Engineering had tended toward an organization with pronounced flatness having 10 divisions, the Bureau of Construction and Repair had developed a more purpose-oriented organization having 5 principal divisions. In many ways, the combined organization was a model of simplicity, clarity, and functional purity. Design, Production, Maintenance and War Plans were the basic substantive responsibilities of the new-born bureau, Figure 1. Radio and Sound became a branch of the Design Division, as did Research. Contracts reported to Production. It is noteworthy to recall that the technical desks at the time reported organizationally to all divisions, although administratively under the Design Division.

Organizations exist to produce, and the concept of a Bureau of Ships testified in terms of:

72 Aircraft Carriers,
8 Battleships,
236 Submarines,
51 Cruisers,
402 Destroyers
505 Destroyer Escorts,
4,080 Large Landing Ships,

and thousands of other craft and conversions, together with research, development and design to make them the finest fighting ships on the seas, and heroic battle damage repairs and fleet maintenance to keep them there. The impact of new technology was particularly striking in electronics. Expenditures for electronics in ships, shore-stations, and development work increased from $6-million in 1940 to more than $1,000-million in 1945. Personnel in the electronics organization in the Bureau of Ships expanded from 39 total officers and civilians in January 1940 to a total of 1205 in September 1945.

In 1942, the Chief of Naval Operations was given "coordination and direction of effort" of the Bureaus and Offices in the preparation, readiness and logistic support of the operating forces. In the Spring of the same year, the powers of Chief of Naval Operations and Commander-in-Chief, U.S. Fleet, were combined in Admiral E. J. King, who also represented the Navy on the new Joint Chiefs of Staff. Coordination was personified. At sea, World War II brought alternation of the Fleet Command in the same ships, unified area commands, and fast carrier task forces, all of which emphasized the functional position of the Type Commanders and their functional organizational relationship with the Bureau of Ships.

Within the Bureau of Ships, the War Plans division was eliminated in August 1941, as all components of the Bureau's organization were then engaged in planning for World War II. Design and

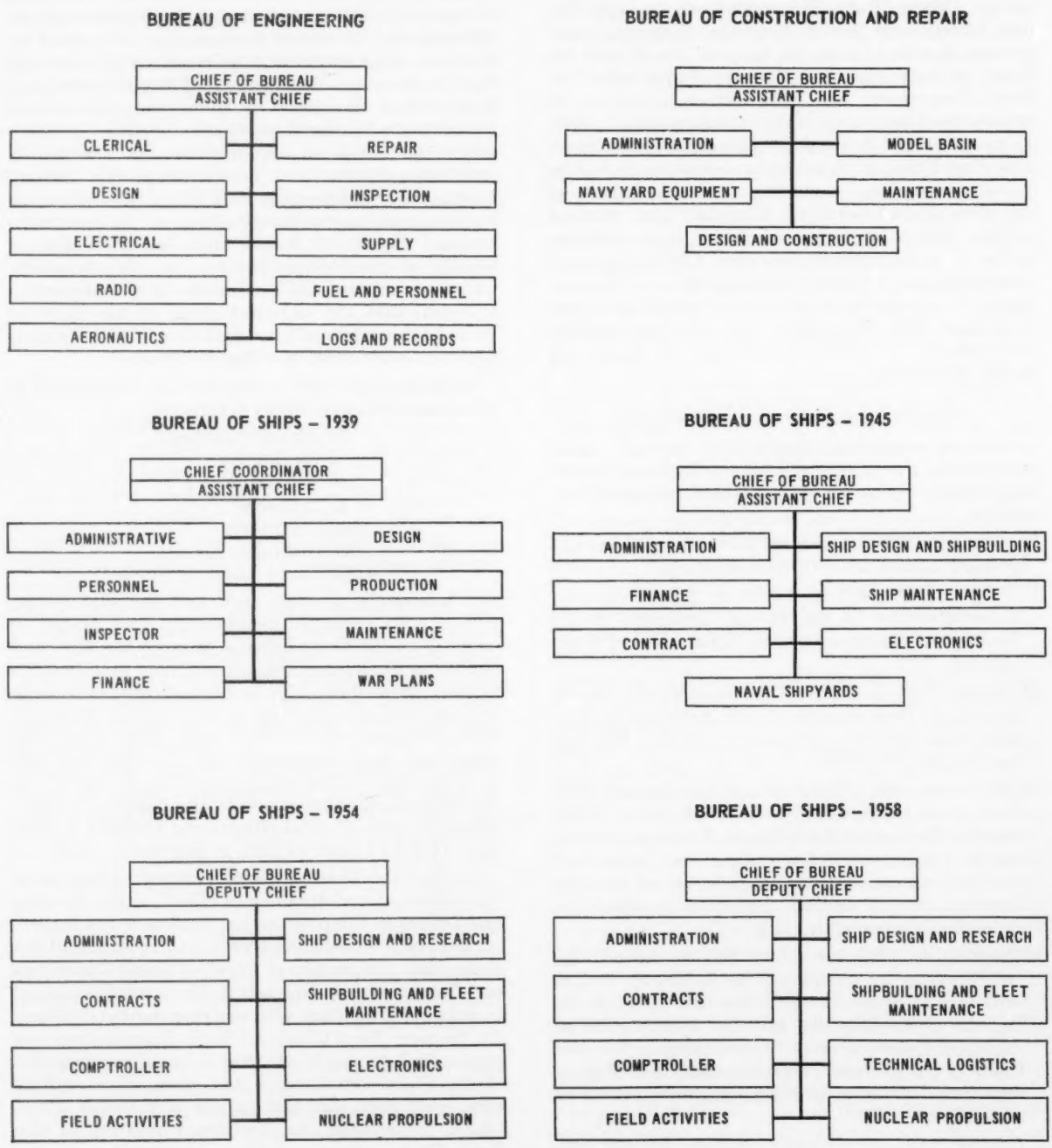


Figure 1. Some stages in the evolution of the Bureau of Ships.

Production were combined into a new Ship Design and Shipbuilding division containing a:

Design Branch,
Contract Branch, and
Construction Branch

A new fiscal division was established in February 1942, an Office of Counsel was created in January 1943, and Contracts was dismembered from Shipbuilding to form a separate division in June 1944. Radio was severed from Design and became a separate division of the Bureau of Ships in October 1942, and, in November 1944, was redesignated the Electronics division. In the peak year of 1945, the organization of the Bureau of Ships comprised 2550 military personnel, 3860 civilian personnel, and 7 division heads reporting to the Chief and Assistant Chief, Figure 2.

BUREAU MANAGEMENT CONTROL

The first year of peace following World War II saw the thorough embodiment of war experience into naval organization, and was perhaps the most friutful management-wise in naval history. It was marked by the redefinition of naval administration along more functional lines, by clarification of the areas of influence of civilian and military, and by the inauguration of bureau management control of field activities.

The elements of naval administration at the departmental level were conceived to be:

Policy Control
Business Administration
Naval Command
Logistics

These elements were assigned broadly to:

Policy Control	Secretary of the Navy	Civilian
Business Administration	SecNav Assistants	Civilian
Naval Command	Chief of Naval Operations	Officer
Logistics	Bureaus of Navy Department	Officer and Civilian

Figure 2. Top executives in the organization of the Bureau of Ships in August 1945.

From left to right: Electronics—Commodore J. B. Dow; Fiscal—Captain P. N. Lauman; Maintenance—Rear Admiral J. J. Broshek; Shipbuilding—Rear Admiral C. L. Brand; Administration—Captain E. E. Roth; Shore—Rear Admiral S. S. Kennedy; Contracts—Rear Admiral F. J. Willie; Assistant Chief—Vice Admiral E. W. Mills; Chief—Vice Admiral E. L. Cochrane.

with primary lines of responsibility for materiel as shown in Figure 3. Distinction was made between consumer logistics, the province primarily of the Chief of Naval Operations, and producer logistics, primarily under civilian control (6). Although the commander-in-chief billet was abolished in October 1945, the combined authority largely continued and CNO was much more influential than in prewar times. The Deputy Chiefs of Naval Operations actually seemed to make a pattern somewhat equivalent to a general staff, while retaining the advantages of the bureau system.

In contrast to a single chain of command, the Navy organization exemplified a bilineal system, with one channel from the Secretary and his civilian assistants to the material bureaus and the other channel from the Secretary through the Chief of Naval Operations and his all-military staff to the bureaus. The organization embodied strong horizontal coordination in lieu of a monolithic vertical relationship, a blending of civilian and military authority and skills from top to bottom, and that quality of flexibility or looseness that seems to benefit organizations all the way from large ones to football teams.

New organizational principles and terms were applied to the field activities, Figure 3:

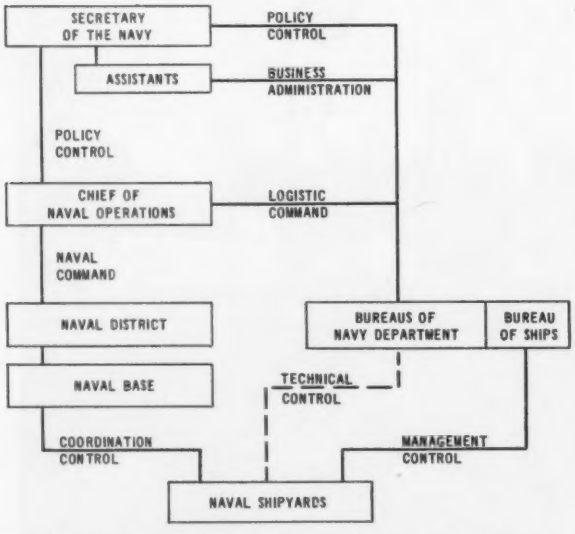


Figure 3. Bilineal functional organization of the Navy Department.

a. Coordination control—the necessary direction of units of a Naval Base to insure adequately integrated relationships; it is often accompanied by the Military Command relationship.

b. Technical Control—the specialized or professional guidance exercised by the bureaus of the Navy Department in technical matters that have been assigned to those bureaus.

c. Management Control—the direction, in other than military matters, exercised by a bureau over a field activity in the routine administration and control of local operating functions.

The concept of management control had an immediate effect on the organization of the Bureau of Ships and of the Naval Shipyards. To provide a historical perspective for evaluation of these changes, let us review the organizational development of the Naval Shipyards.

THE NAVAL SHIPYARDS

From their establishment in 1800, the original five Navy Yards were under the direct control of the Secretary of the Navy. When the Board of Commissioners was formed to assist the Secretary, the Navy Yards were placed under this Board. Beginning in 1842 with the establishment of the bureau system, some overall management was exercised by the Bureau of Navy Yards and Docks. The Commandants reported to the Chief of that Bureau, who exercised general supervision of administration of the Yards (7). In 1862, the name of the Bureau of Navy Yards and Docks was changed to Yards and Docks, and with it went the only centralized management of Navy Yards on the departmental level. Fractionation of control was further encouraged by the founding of the Bureaus of Equipment, Navigation and Steam Engineering.

The dispersion in bureau organization for ship work which took place in 1862 was reflected directly into the Navy Yard organizations. Each bureau had its own independent department in each of the Navy Yards. A typical Navy Yard organization about 1900 comprised the five major departments of Construction and Repair, Steam Engineering, Yards and Docks, Equipment, and Ordnance, plus the Captain of the Yard, General Storekeeper, Medical Officer and Pay Officer, Figure 4. As direct lines of authority and responsibility flowed in parallel from each bureau to its field agent, there was widespread duplication of personnel and facilities. At one Navy Yard, there were 5 machine shops, 3 foundries, and 3 different power plants. Various other elements of the Shore Establishment naturally grew up around the Navy Yards, such as ammunition and supply depots, training and recreational facilities, and hospitals; these are referred to in Figure 4 as Other Military Activities.

On 26 January 1909, Secretary Newberry issued a general order which directed drastic changes in the organization of the Navy Yards. All industrial work was consolidated in a Manufacturing Department under a Naval Constructor who was to serve as Principal Technical Assistant to the Command-

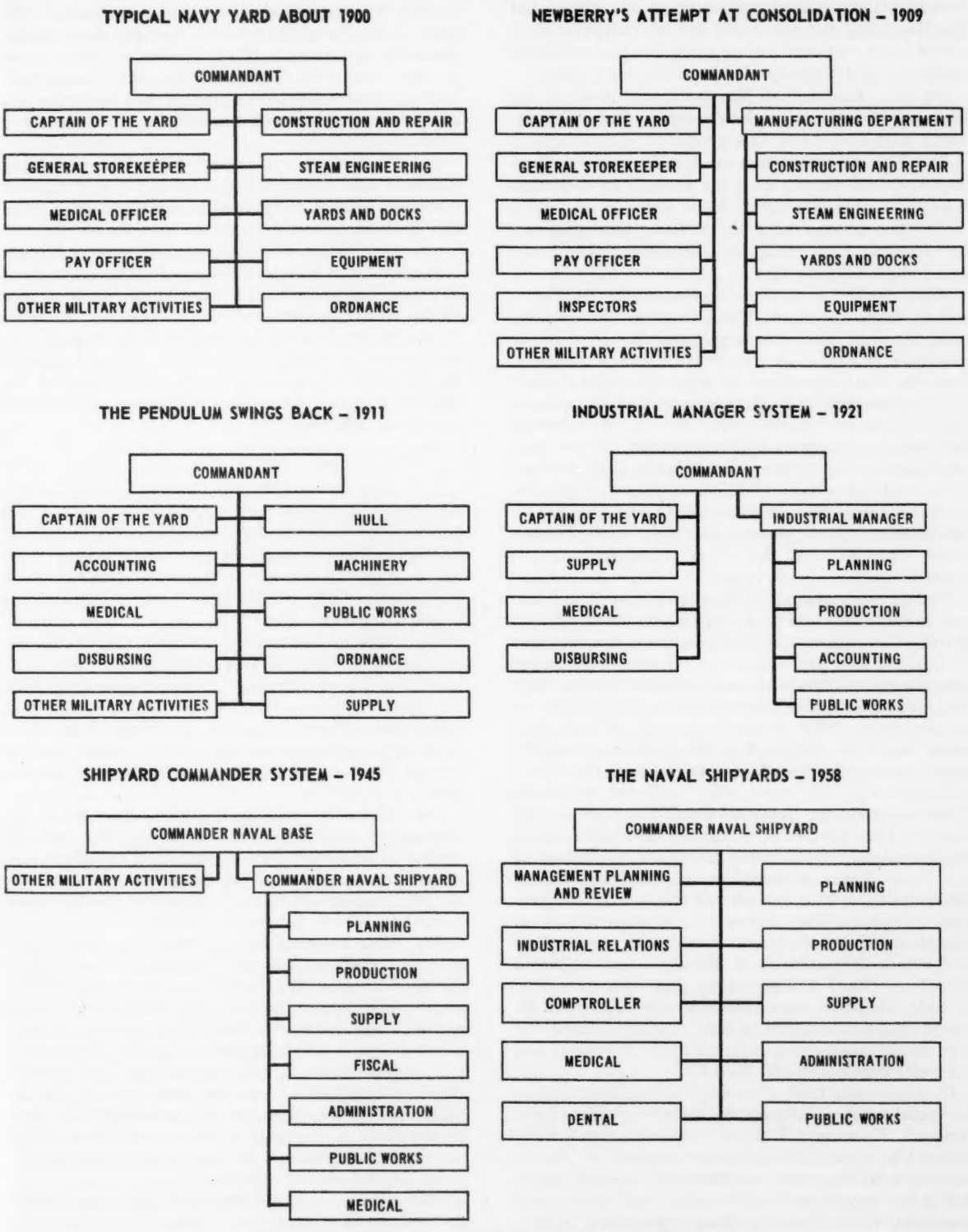


Figure 4. Evolution of the organization of the Naval Shipyards.

ant. Secretary Newberry had made a bold stride toward a functional organization in the Yards, but the Navy was not yet ready for it. Three developments were required before a similar plan could be executed by Secretary Forrestal 36 years later:

(a) The transfer of Naval Constructors to the Line of the Navy as Engineering Duty Officers along with the Naval Engineers,

(b) The amalgamation of the Bureau of Construction and Repair with the Bureau of Engineering to form the Bureau of Ships, and

(c) The concept of a Naval Base, first proposed by Admiral E. J. King, to segregate the military and industrial activities.

When Meyer came in as Secretary, the pendulum swung back to Navy Yard organization divided along bureau lines. He separated the yard shops into two principal divisions, Hull and Machinery, being in effect separate field activities of the Bureau of Construction and Repair and the Bureau of Steam Engineering. Secretary Meyer did recognize the need for improved departmental control and established a Director of Navy Yards. This new position violated a basic principle in that the Director of Navy Yards had unlimited authority but no responsibility, particularly financial. The Bureau chiefs objected and the effort lasted only a few years.

One of the prime difficulties in World War I was the organization and administration of the Navy Yards. To improve coordination, both the Bureaus of Construction and Repair and Steam Engineering created Shore Establishment sections within their organizations. The separate sections were combined in September 1921, at the suggestion of Rear Admiral David W. Taylor, to form the Navy Yard Division under the Assistant Secretary of the Navy. Unfortunately this new office suffered from the same violation of organizational principle as did Meyer's Director of Navy Yards. Meanwhile, progress was being made in the internal organization of the Navy Yards as Secretary of the Navy Edwin Denby, also in 1921, introduced the Industrial Manager System. The Industrial Manager concept placed industrial Planning, Production, Accounting and Public Works under a Manager responsible to the Navy Yard Commandant, but left industrial Supply, Medicine, and Administrative Services directly under the Commandant, Figure 4. Still the new organization was a large stride forward, and survived through World War II.

In September 1945, Secretary of the Navy James Forrestal wrote: "During the past 6 months, Fleet Admiral King and I have devoted considerable thought to ways in which improvements in our industrial efficiency can be obtained, without sacrificing the recognized values of present navy yard organization or impairing their outstanding technical performance in serving the operating forces. This matter has been thoroughly discussed with interested members of Congress, with a number of leading private industrialists, and with various officials of the Navy Department and the shore establishment. As a result of our studies, we have come to the conclusion that there are three important prerequisites to securing greater and enduring improvement in the operating efficiency of the navy yards:

(a) First, we must centralize the internal management and technical control of the industrial activities of each navy yard in the hands of a properly trained, properly empowered executive.

(b) Secondly, we must concentrate adequate authority for the departmental administration of all of these industrial installations in a single agency of the Navy Department.

(c) Thirdly, we must integrate the logistic activities in the locality of each navy yard under a single military command so that the needs of the operating forces can be met expeditiously and with maximum efficiency."

Implementing directives provided that:

(a) "The officer ordered to command of a U.S. naval shipyard shall be technically trained in the building and repair of ships and shall have had substantial previous experience in the technical and management phases of such work, both in U.S. naval shipyards and in the Navy Department. Such commanding officer may have been designated for engineering duty only."

(b) "The *administration* of the work of the entire shipyard, and the responsibility for the results produced by all activities of the shipyard, shall be the direct responsibility of the Bureau of Ships, acting through the commanding officer of the shipyard, and such responsibility is no longer divided among the several bureaus and offices as heretofore."

(c) "Naval bases, including each shipyard as one component activity, shall be under the *military command* and *coordination control* of an officer designated commandant of the naval base, who will be directly responsible to the commandant of the naval district in which the base is located."

(d) "The internal organization of a U.S. naval shipyard shall include the following main departments: Planning, production, public works, supply, fiscal (including accounting and disbursing), medical, and administration (including matters of military personnel administration, security, fire protection, communication, plant protection, and various other administrative services required by the departments of the shipyard). In addition there shall be attached to the staff of the commanding officer an industrial relations division and a management planning and review division."

Here clearly was a framework for organization and industrial management striking in its logic and simplicity. Here finally was functional coordination in the field activities, as had already been achieved

at the departmental level, of all the elements going into shipbuilding and ship maintenance.

From a departmental point of view, management control by the Bureau of Ships has provided better distribution of personnel, funds and work load, better integration of industrial facilities and the planning therefor, and wider interchange of improvements between the Naval Shipyards. From the shipyards' point of view, the arrangement has provided a single departmental representative who is cognizant, responsible and accountable, a close-knit relationship of all organizational elements at both the bureau and shipyard level for material support of the Fleets, and a knowing source of information on the work of the other Naval Shipyards. From the forces afloat point of view, management control by the Bureau of Ships has led to standard organizations and procedures so that visiting ship companies are quickly at home in the different shipyards, to immeasurably improved advanced planning for regular overhauls, and to integrated and closer control of funds.

The Bureau of Ships still did not have complete control of the financial support for operation of the Naval Shipyards. The advent of the Performance Budget in May 1950 placed in the hands of the Bureau of Ships, and in turn of each Shipyard Commander, the management tools required for composite control of personnel and funds. Now after decades of evolution the eleven Naval Shipyards and their management bureau are organized and work as a team toward the organizational objective —Ships.

MID-CENTURY CHANGES

The National Security Act of 1947 and Amendments of 1949, which created a Secretary of Defense over the military departments (19), had little direct effect on the internal organization of the Bureau of Ships. In February 1951, the Chief of the Bureau of Ships was delegated responsibility for coordinating ship repairs and conversions within the Department of Defense, and with other Government agencies during wartime or national emergencies.

Evolution of the Bureau of Ships continued, keeping those organizational features which seemed to be working well, and revising others to improve efficiency and to meet changing conditions. Illustrative of this process which occurs in any dynamic organization are the following changes in the Bureau of Ships during the period from 1946 to 1958:

July 1946—Guided Missiles section, headed by a Bureau of Ships Guided Missile Coordinator, established in the Shipbuilding division.

December 1946—Management Planning and Review branch and the Field Personnel Planning branch consolidated under the Naval Shipyard division.

January 1947—Additional responsibility as Coordinator and Deputy Coordinator for Nuclear Matters assigned to the Director of Ship Design and Deputy Director of Design respectively.

May 1947—Office of Mobilization Planning established as staff to the Chief.

September 1947—Billets for Assistant Chief of Bureau for Ship Design and Shipbuilding, and Assistant Chief of Bureau for Fleet Maintenance were disestablished. Their duties and responsibilities were amalgamated under a new billet titled Assistant Chief of Bureau for Ships, with four principal components:

Research
Design
Ship Technical
Material Control

December 1947—Billet of Assistant Chief of Bureau for Administration established in lieu of Director of Administration.

June 1948—Director of Naval Shipyard division redesignated as Assistant Chief of Bureau for Field Activities.

August 1948—Nuclear Power branch established in the Research division to consolidate the handling of nuclear matters.

August 1948—Industrial Capacity division established under the Assistant Chief of Bureau for Field Activities.

December 1948—Contract division reorganized.

June 1949—Research division removed from under the Assistant Chief of Bureau for Ships, and headed by a Division Director reporting directly to the Chief.

August 1949—Director of Research redesignated as Assistant Chief of Bureau for Research and Development.

November 1949—Ship-Technical division reorganized to consolidate 8 branches for more efficient operation.

June 1950—Office of Planning established as staff to the Chief.

November 1950—Research and Development divisions reorganized and functions redefined.

April 1951—Organizational responsibilities within the Bureau defined to assist the Chief in discharging his duties as Coordinator of Shipbuilding and Conversion for the Naval Establishment.

June 1952—Budgetary and fiscal functions consolidated throughout the Ships division.

November 1952—Nuclear Power division transferred from under Assistant Chief of Bureau for Research and Development to Assistant Chief of Bureau for Ships.

April 1954—Value Engineering established as staff to the Chief.

July 1954—Assistant Chief of Bureau billets for Research and Development and for Ships disestablished, and new billets for Ship Design and Research and for Shipbuilding and Fleet Maintenance established, together with the transfer of all functions and personnel of the Ship Design division.

August 1954—Material Control division reorganized under four functional assistants.

July 1955—Assistant Chief of Bureau for Nuclear Propulsion established.

August 1955—Fiscal Director redesignated Comptroller.

April 1956—Ship Technical division disestablished, and Ships division, Hull division and Machinery division established, together with redesignation of the Material division, all under the Assistant Chief of Bureau for Shipbuilding and Fleet Maintenance.

May 1956—Advanced Studies section formed in the Preliminary Design branch of the Ship Design division.

June 1956—Comptroller Accounting division reorganized.

September 1956—Field Activities divisions reorganized.

March 1958—Special Assistant for the POLARIS Program established as staff to the Chief.

During this mid-century period, 14 significant changes were made in the organization of the divisions under the Assistant Chief of Bureau for Electronics.

As of June 1958, the regulatory documents determining the organization of the Navy Department and the position of the Bureau of Ships therein were General Order 5, Policies and Principles Governing the Distribution of Authority and Responsibility for the Administration of the Naval Establishment, dated 4 June 1953; General Order 9, Organization of the Operating Forces of the United States Navy, dated 16 November 1955; General Order 19, Relationship of Shore Activities of the Naval Establishment and Functions and Duties of Certain Shore Commands, dated 20 May 1949; and United States Navy Regulations with changes to that date.

BUSHIPS REORGANIZATION 1958

The objectives of the reorganization of the Bureau of Ships in June 1958, as set by the Chief, were:

(a) To strengthen the basic organization of the Bureau along more functional lines, and

(b) To provide for better integration of the technical aspects of electronics into the ship system.

The scope of the reorganization of 1958 was doubtless the most extensive since the creation of the Bureau of Ships. Whereas most earlier reorganizations had involved only the regrouping of divisions or branches, or the consolidation, establishment or disestablishment of a few organizational elements, implementation of the changes in 1958 extended from transplanting people and functions on an individual basis through every organizational level up to Assistant Chief.

The principal organizational moves (2) were to:

(a) Disestablish the billet of Assistant Chief of Bureau for Electronics and all staff and divisions thereunder.

(b) Create a pattern of hull, machinery and electronics disciplines in the chief organizational segments of the Bureau.

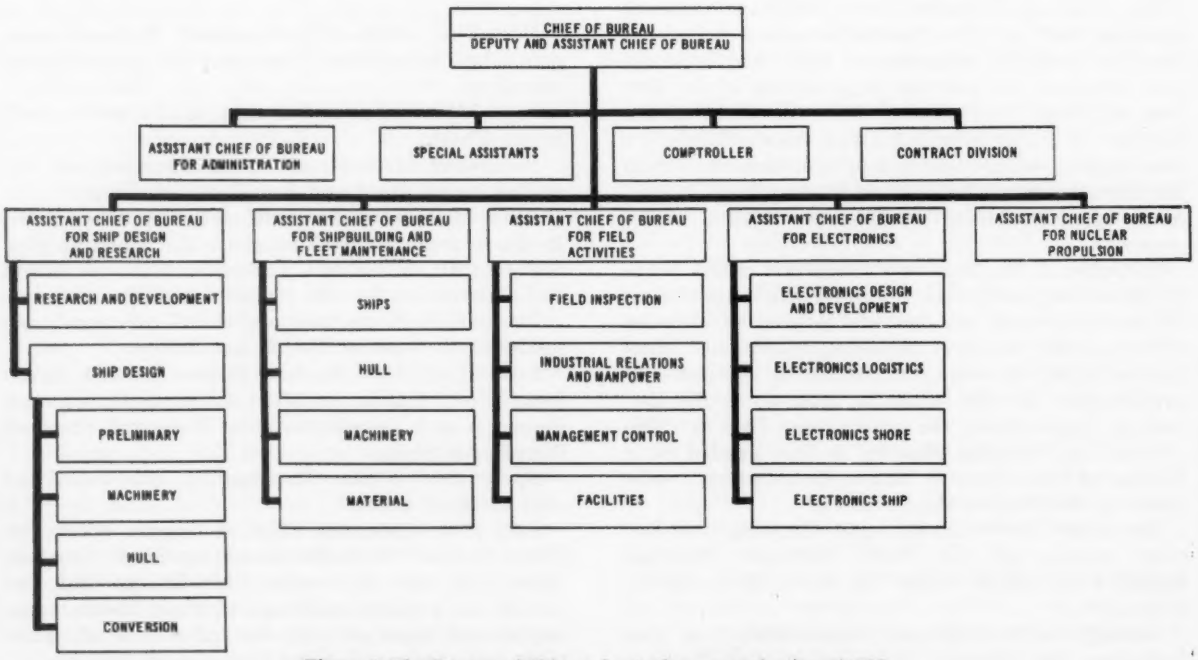


Figure 5. The Bureau of Ships prior to the reorganization of 1958.

(c) Augment electronics capabilities in the Ship Type branches.

(d) Establish a new branch called Electrical and Electronics under the Director of Ship Design.

(e) Incorporate Shore Electronics under the Assistant Chief of Bureau for Field Activities.

(f) Establish an Assistant Chief of Bureau for Technical Logistics to be responsible for all component matters, including material, in all technical areas.

(g) Amalgamate progressively the Material branches responsible for hull, machinery and electronics hardware.

(h) Leave the Assistant Chief of Bureau for Shipbuilding and Fleet Maintenance responsible only for ship type matters complete with the electronics function.

(i) Complete evolution of the Ship Design organization along functional lines.

(j) Amalgamate elements of the Bureau devoted to weapons effects and ship protection.

Although consolidation of the Design divisions had spearheaded merger of the Bureaus of Construction and Repair and of Engineering, organizational amalgamation actually lagged behind other areas in the Bureau of Ships. The Preliminary and Hull Design branches were still functioning largely as they had in C. and R. days (20), and the Machinery Design branch continued to do both preliminary and contract design of systems originally under BuEng less electronics, Figure 5. The reorganization of 1958 provided for introducing machinery and electronics disciplines into the hitherto naval architecture preserve in the Preliminary Design branch, for creating the same triumvirate of disciplines in the contract design stage by the establishment of an Electrical and Electronics Design branch to join the Hull and Machinery Design branches, and for rechecking completely machinery and electronics features in the contract design stage as hitherto had been done only for hull design features, Figure 6. In addition, the responsibility of the Director of Ship Design for ship systems was strengthened by consolidating the Piping sections in Machinery and Hull Design, and by introducing the design of electronics and fire control systems into the Ship Design division. The basic selection of propeller characteristics was reemphasized as a Design division responsibility, vested in the Machinery Design branch.

In the Ship Type area, the organizational pendulum completed a full swing in the last decade of history of the Bureau of Ships. From 1948 when the Ships division was surrounded under the same Assistant Chief by the following, these adjoining divisions were separated in the years indicated to other Assistant Chiefs:

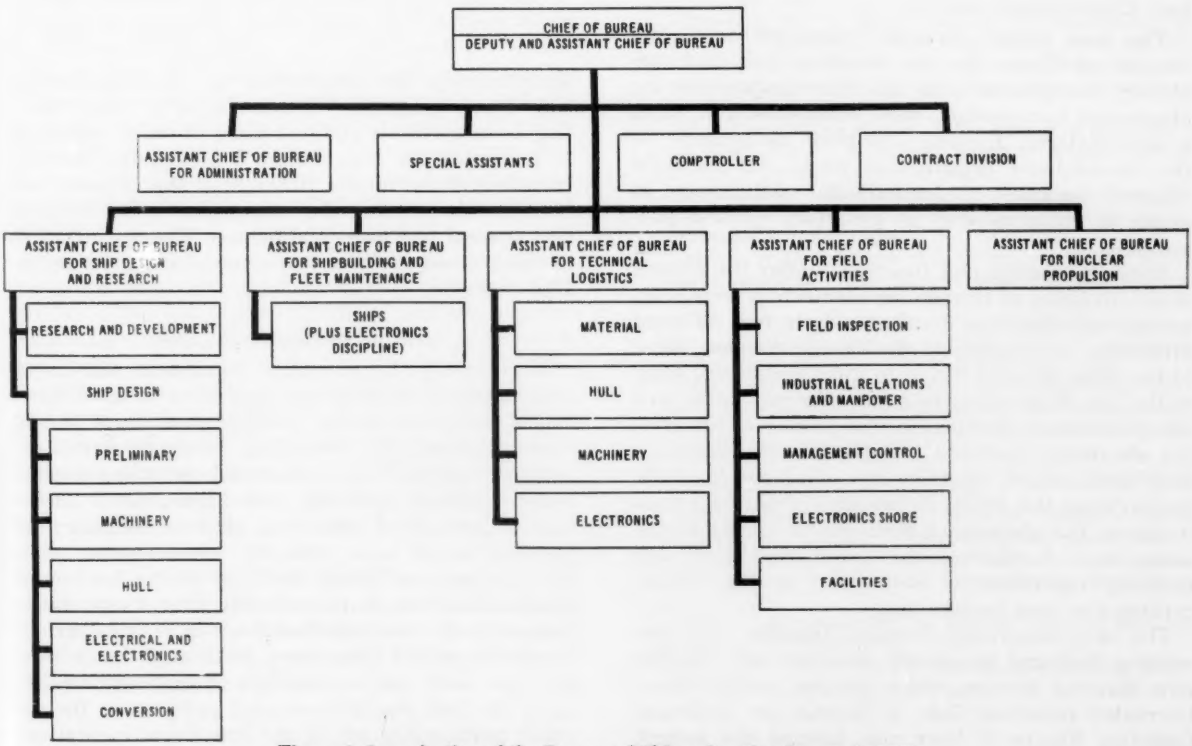


Figure 6. Organization of the Bureau of Ships after the changes in 1958.

Research	1949
Design	1954
Nuclear Power	1955
Technical	1958
Materials	1958

Now the Assistant Chief of Bureau for Shipbuilding and Fleet Maintenance is able to devote himself wholly to the Ships division, Figure 6, and to the purpose-oriented functions of the Ship Type branches which coordinate and integrate by bow number supporting specialist areas throughout the Bureau of Ships. The 1958 reorganization also strengthened the pivotal position of the Ship Type branches by the introduction of individuals versed in electronics to complement the machinery and hull backgrounds already available.

Some consideration was given to movement of Shore Electronics to the Bureau of Yards and Docks, but the final position was an intermediate one, under the Assistant Chief of Bureau for Field Activities. Here in Field Activities lines of communication would be shortened relative to Electronics Shop matters in the Naval Shipyards, Electronics Maintenance and Military Construction program matters at Bureau-managed activities, harbor defense, and liaison with Industrial Managers through whom shore electronics in continental U.S. and overseas is handled. Organizational location in Field Activities provided a common point of contact for the Bureau of Yards and Docks on all Military Construction matters.

The two major material organizations in the Bureau of Ships, the one handling hull and machinery components and the other responsible for electronics components, were consolidated to form a new Material division. Complete realignment of the consolidated organization could not be fully effected because of fundamental differences in origin of material and in inventory control procedures.

Hence personnel and functions under the former Assistant Chief of Bureau for Electronics were fractioned individually and collectively in five different directions, some going to the Design division, some to the Ships division, some to Field Activities, some to the new Material division, and the remainder to a new Electronics division. In this process of integrating electronic functions broadly into the Bureau's ship organization, caution was exercised to avoid jeopardizing the Bureau's position of national eminence in the electronics field *per se* while, at the same time, furthering the established and still growing importance of electronics in ship design, construction and maintenance.

The new Electronics division, together with the existing Hull and Machinery divisions and with the new Material division, were grouped under a newly-created Assistant Chief of Bureau for Technical Logistics, Figure 6. Here was formed the largest organizational repository of technical talent in the Bureau of Ships, composed of authorities in their own particular technical areas and positioned independently to provide technical support throughout the Bureau of Ships. Unquestionably, the organizational posture of Technical Logistics must continue to be oriented to technical support of purpose-oriented Ship Design, Shipbuilding and Fleet Maintenance, and Field Activities. This principle was considered basic to the entire reorganization of 1958.

Protection from atomic, bacteriological and chemical weapons was a function discharged in several islands of interest within the Bureau. As a part of the reorganization, ship and personnel protection, together with the entire field of shock and with the planning and coordinating of field tests, was consolidated under Preliminary Design to facilitate incorporation of findings early in the design state of new construction. Overall program administration of radiological defense was left under the Research division but relocated to the Applied Sciences branch.

Quantitatively, the reorganization entailed significant shifts of personnel:

Assistant Chief	Before	After
Electronics	670	0
Ship Design and Research	560	590
Shipbuilding and Fleet Maintenance	1230	340
Technical Logistics	0	1470
Field Activities	260	320
Others	1040	1040
	3760	3760

Qualitatively, the structuring of the organization had been simplified. Chronologically, electronics had been given its rightful place of early influence in the process of ship design. Functionally, the distribution of disciplines throughout the Bureau had been paralleled, and the responsibility for integration thereof had been highlighted. The organization of the Bureau of Ships had attained maturity on its 18th birthday.

DOD REORGANIZATION 1958

Historically, the two most significant schools of organizational doctrine for the defense of the United States have been said to be Decentralization versus Centralization (21). Secretary James Forrestal reportedly reasoned that a vast and sprawling organization becomes unwieldy and unresponsive under highly centralized direction, that a Secretary of Defense would have difficulty administering such an organizational giant, and that strong horizontal coordination was more workable than a monolithic hierarchy of command. Secretary of War Robert P. Patterson, on the other hand, advocated the unitary principle with one vertical line of organization, despite the fact that this concept compresses the civilian partnership out of the line departmental organization, and the Rockefeller Committee likewise

favored a single line of command but with the civilian secretaries in operational control. Steadily the trend has been toward centralization, from a National Military Establishment in 1947 which was essentially a federation of the three military departments, to a Department of Defense in 1949 coordinating three semi-autonomous departments, to the Reorganization of 1953 with its broad and powerful civilian staff under the Secretary of Defense and with increased authority in the Chairman of the Joint Chiefs, and now to the Reorganization of 1958 with centralized control in the Secretary of Defense and the Chairman of the Joint Chiefs. The Reorganization Act of 1958 "clearly and unequivocally establishes the Department of Defense as a composite organization under the direction, authority and control of the Secretary of Defense" (22). The Navy Department operates as one of the three military departments in full support of the Office of the Secretary of Defense, the Joint Chiefs of Staff, and the combatant command structure.

Two principal lines of control are provided "a line of operational command from the President and the Secretary of Defense directly to the combatant forces, and a line of administration and support through the military department" (22). As the military command function of the Chief of Naval Operations is de-emphasized by the Reorganization Act and as his administrative and support functions are emphasized, it is inevitable that some organizational realignments within the Shore Establishment will be forthcoming. Great progress has been made in shortening the lines of communication and direction between the Commander in Chief and the combatant commands, in unifying the Services and enhancing vital teamwork, and in readying the Defense Department for wars of all temperatures. The Bureau of Ships is organized and dedicated to serve this team in the functional area of its responsibility.

Evolution continues or an organization stagnates. From its simple structure and needs 150 years ago, the Navy has become an infinitely complex and dependently technical organization. History provides one guide source for extrapolating to the future. Another guide source is derived from organizational principles, the synthesized experience of others. Part II of this study examines such principles.

EDITOR'S NOTE: Part II of this paper, together with overall conclusions, will be published in the May 1959 issue of the JOURNAL.

ACKNOWLEDGEMENTS

Appreciation for the incentive to make this study is expressed to Rear Admirals A. G. Mumma and L. V. Honsinger, USN, presently Chief and Deputy Chief of the Bureau of Ships.

Acknowledgement for their astute and invaluable collaboration in developing the recommendations of the Board To Implement Reorganization Of The Bureau Of Ships, June 1958, is made to Captains W. A. Brockett, E. J. Hoffman, J. H. Allen, and N. Sonenshein, USN, and to Mr. C. E. Wilkenloh, Recorder.

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A reorganization of the material departments of the British Navy, corresponding in part to the material bureaus of the U. S. Navy, has been completed during the past year. Four large material departments, in addition to a small group of scientific departments, have been set up under the Controller of the Navy. Each department is headed by a Director General. The four departments are the Ship Department, the Weapons Department, the Aircraft Department, and the Dockyard and Maintenance Department.

The Weapons Department is responsible for the design, production, and installation of all weapons and weapons systems, radar, communications and navigation equipment. The Aircraft Department is responsible for ensuring that air material requirements are met and for satisfactory operation of air material in service. The Dockyard and Maintenance Department is responsible for the repair and maintenance of the fleet and for the provision of all necessary marine services and facilities to the Fleet. This department accomplishes its functions through three divisions, the Dockyard Division, the Fleet Maintenance Division and the Marine Services Division.

The Director General of the Ship Department is the principal technical adviser to the Board of the Admiralty and the final authority on ship design below the board. The Ship Department is responsible for the design and construction of naval ships, their propelling machinery, auxiliary machinery and electrical installations. It operates through five divisions, each under a Director—the Naval Construction Division, the Marine Engineering Division, the Electrical Engineering Division, the Ship Production Division, and the Naval Equipment Division. It is planned that elements of these divisions will work together in various combinations to provide close integration in ship design, production, financial control and administrative support. For instance, four ship groups have been formed to deal with ship types—aircraft carriers, submarines, cruisers, and destroyer types. Each of these groups contains elements of each of the divisions. Specialists groups also will be formed, dealing with technical fields which cut across division lines, such as lighting, ventilation, noise and vibration.

—from THE SHIPBUILDER AND MARINE ENGINE-BUILDER
November, 1958

A plasma-flame torch, making available for industrial use temperatures more than double those at the surface of the sun, has been developed by the Thermal Dynamics Corporation. To achieve this performance, an electric arc is established in an annular space between a center electrode and a concentric electrode. A gas, such as nitrogen or hydrogen, is passed through the annular passage under pressure, forming a plasma jet downstream from the arc. The major feature of this design is the successful spacing of the arc away from the walls of the electrode passage. The temperatures achievable with this torch are four to five times those resulting from an oxy-acetylene flame, and are expected to rapidly engender new industrial techniques.

—from MECHANICAL ENGINEERING
November, 1958

"U.S. NAVAL INSTITUTE PROCEEDINGS"

McLINTOCK'S CALCULATED RISK

ACKNOWLEDGEMENT

This article is reprinted from the January 1959 issue of "U.S. Naval Institute Proceedings"; Copyright 1959 by U.S. Naval Institute. The author is William McFee.

ON THE 17th of June, in the year 1900, the British tramp steamer *Titania*, 5,000 tons deadweight, of London, with a crew of twenty-two, left Cape Town, South Africa, for Buenos Aires, in ballast. She had come from Melbourne.

In Melbourne the chief engineer had been offered a job as manager of a factory. His pay as chief was £18 a month—about $85.00 at that time. The shore position paid much better—£25—and a house. Skilled men were at a premium in Australia. The captain cabled to the owners in London. The second engineer—the first assistant—had a chief's ticket, had been in the ship two years, and he was, the chief said, highly competent. William McLintock was only twenty-three; in fact he had been given his ticket at an unusually early age, but he had made a sound impression on both his chief and the captain. How competent he turned out to be we shall see. In addition, the captain cabled, there was a young fellow in Melbourne—a mechanic—who was looking for a passage home to Englnd. He would sign on as a junior.

The owners, the Howard Steamship Company of Leadenhall Street, were reluctant to lose their chief engineer but they would not stand in his way. He had been in the ship since she was built in Sunderland in 1885, and they could rely on his judgment of the second engineer, in which Captain MacMillan, a Scot from the Hebrides, concurred. The owners cabled their assent, and Captain MacMillan signed off his chief engineer and paid him, and then proceeded to sign on William McLintock as chief, and the others in series.

This brought Mr. Ferguson—the second-assistant, to be first. He was in his forties, almost the oldest man on the ship. He was the roving type of seaman, never long on any ship. He had been in big liners, he said, from which he had mysteriously resigned. It was always the fault of some other person. He would name no names, but he had left, rather than be put upon. He disliked responsibility, yet paradoxically he resented not being promoted to chief when the other man left. He did not mix socially with the other officers, but vanished into his cabin when off watch, where he sat reflecting on the injustice which a man could meet on the high seas. He had served his time at Denny's yard, on the Clyde, where big private yachts and liners were built, and he conveyed the impression that he was lowering himself to serve in tramps, and would shake the dust from his shoes when he was paid off. He told the donkey-man, a friend of his, that something would happen when they promoted a whippersnapper like McLintock to be Chief. He was, Mr. Ferguson said, green, green as grass, and wet behind the ears.

A tramp steamer in ballast, in those days, was the gypsy of the Seven Seas. She was a homeless wanderer. The *Titania*, for instance, was registered out of London, but she had not seen her home port since she was launched. She had to make long voyages in ballast in search of cargo. She had no deep tank she could fill with water to keep her down on such voyages. Her propeller, on an even keel, was one third out of the water. She resembled a balloon. When she pitched, the engines alternately raced and almost stalled. Liners, as a rule, had electro-hydraulic governors. which controlled the engine speed under such

conditions. Tramps had to take it. They were built to take it. They carried Britain's overseas trade. At that time there were ten thousand of them steaming over the Seven Seas.

Leaving Cape Town, all went well, Buenos Aires and Cape Town are almost exactly on the thirty-fifth degree of latitude south of the Equator. It was a winter voyage in ballast, and they expected bad weather—what Captain MacMillan called dirty weather. It is 3,700 miles between the two ports, against a strong current from the Falkland Islands, and prevailing westerly winds. As the *Titania* threshed slowly to the westward, the wind and sea increased. She rolled and she pitched. The fiddles were on the tables, and everything was lashed down. Lifelines were rigged from the forecastle to the bridge. The firemen, dumping the ashes at the end of their watch, risked their lives carrying the buckets to the rail. Their bunks were awash. It was a normal voyage. winter South Atlantic. So long as the propeller kept turning, there was nothing to it.

Now and then the *Titania* took a lurch and for a moment she would be on her beam ends, and then pitched so violently that the propeller came right out of the water. On one of these occasions she came down in a hollow—a veritable deep valley in the sea —and hit the water with blow like an explosion. It was such a smashing concussion that everybody thought she had hit a rock or a submerged wreck. They ran out on deck and stared around, but saw only sky and sea, with a few Cape pigeons. A great white-winged albatross, watching the galley chute with a beady eye, floated like a glider over the bridge. The third mate, on watch, saw nothing else. It was a false alarm. Mr. McLintock, who had slowed his engines revved them up again to full speed.

That afternoon, however, Mr. Ferguson, who went on watch as usual at four o'clock, was feeling the main bearings and the connecting-rod ends, when the speed of the engines suddenly increased from 60 to over 200 revolutions per minute. It made him start back in alarm. The noise was terrific. The Chief, having a cup of tea in his room, came down the ladder like lightning. Together they rushed to the maneuvering valve and whirled it shut. For a moment there was a dazed silence. Then, with a shattering roar, the safety valves lifted. Mr. McLintock sent Mr. Ferguson into the fire room to close the funnel damper and to order the ashpit dampers closed. Then he took a slush lamp from the rail and went along the shaft alley to the stern tube. All was well. Bearings were cool and the stern tube had the usual drip. Tunnel-well was as usual. He came back to the engine room looking extremely grave. Climbing the engine ladders to the deck, he went along aft. He heard the safety valves give an occasional hiccup, as if they were going to lift. He went right aft and, leaning over as far as he could, he looked at the propeller. It was not there any longer.

His face still grave, he went forward to the bridge. Captain MacMillan was waiting for him at the chart-room door.

"She's gone, Captain. We're out of control."

For a moment the Captain did not speak. They were cast away on the wide Southern ocean, in winter, some 1,200 miles from their nearest port. There was no radio in those days. They would have to depend upon themselves.

It was already nearly dark. The long Antarctic winter night was closing in on them. The first mate was getting the two red lights, the international signal for "out of control," hoisted on the signal halyards.

The Captain, not yet thirty himself, asked his twenty-three-year-old chief engineer,

"Can ye do it?" He meant, take out the broken shaft and put in the spare one with the spare propeller.

"Aye, I can do it. But its risky," Mr. McLintock said.

"I'll take the risk if ye can do the job. Say the word, Mac."

It was a momentous decision. Mr. McLintock did not hesitate. He said he would do it.

It was now dark. Mr. McLintock was under no illusion about the task. It was an appalling situation. He had assisted at such jobs at home, in a drydock with adequate gear and many men—skilled men—on terra firma. It was a slow, laborious business even then. He decided to sleep on it. He would need all his youth and strength and courage to keep going.

Next morning, early, the Captain called the mates and engineers to his cabin to hear his decision. The Chief Engineer said he could do the job, draw the broken shaft, put in the spare and fit the spare propeller, which was in the after 'tween-deck, All hands would turn to and render him every assistance. That included himself, the Captain. Everybody but the cook. What did they think?

Some of them thought very little of the scheme. How were they going to get the spare tail shaft out of the lower hold and into the shaft alley? How could they get the spare propeller over the side in a sea like this? Once the broken shaft was drawn from the stern tube the sea would pour in. It would sink her. But when the Captain categorically asked them, would they go along? they fell silent.

All but Mr. Ferguson, the new first-assistant. He said they should take to the boats and make for Tristan de Cunha. He would have nothing to do with such a lunatic idea as changing a tailshaft at sea. It was a scheme to imperil all their lives.

Mr. McLintock looked at his first assistant but said nothing. Then he looked at his Captain. This was bad, bad. The first assistant is the executive officer down below.

"Mister," Captain MacMillan said sharply. "Is that your decision?"

"It's lunacy!" the first assistant grumbled. He saw

himself with a tale to tell—being rescued from Tristan de Cunha and being sent home as a distressed seaman. "Lunacy!"

"So you won't turn-to?"

"We'll be all drowned once the stern tube's open."

"All right, my laddie," the Captain said. "We'll leave you out of it. Ye'll go to your cabin and stay there until I say ye can come out. I'll attend to your business when we get home."

"If you ever do!" Mr. Ferguson muttered as he turned away.

(It must be emphasized that Mr. Ferguson was sincere. In his view he was the only sane man on the ship. As usual, he was misunderstood. His vast experience was available and it was, as usual, rejected.)

"Everybody else turn to," said the Captain, closing the conference.

They began at once. The mate started to make a sea-anchor out of lifeboat oars and awning-spars, lashing them into a triangle, covering it with some awning canvas, to the apex of which—inverted when in the sea—was attached a five fathom length of mooring chain with a kedge anchor. The ballast pump was put on the after peak, and the two after double-bottom tanks, to raise the stern. The forward tanks were pressed up, and eighteen feet of sea-water run into the forward hold. When the sea-anchor was ready they passed a three-and-a-half inch wire hawser through the chock on the forecastle head and made it fast to the strap which had been made fast to the sea-anchor. A winch lifted it up and it was dropped over the side, where it sank. It suddenly appeared on top of a wave, ahead. The wire was made fast to the windlass and the ship steadied. Her drift was checked, and she lay head to wind and sea. Then they rigged two tarpaulins to the mizzen mast rigging, where they acted like stuns'ls.

All this was only the beginning. Down below, the engineers were disconnecting the broken tailshaft, and the next section—a short piece called the bobbin shaft, about ten feet long, which had to be removed to allow the tailshaft to be drawn from the stern tube. These pieces of steel were about ten inches in diameter, with heavy flanges for the bolts. They weighed between one to two tons each. The confined space in the shaft alley made the slacking of the bolts, which were three inches in diameter, difficult. They were very tight and the main engines had to be turned to bring them all into position. The turning engine had been put into gear by the chief. The carpenter, as soon as he had finished making the sea-anchor, made stools to take the shafts, with wedges to hold them steady. To draw the shaft they rigged heavy chain tackle to the shaft-bearing-stools. Now the sailors and coal-passers started to take bunker coal forward in wheelbarrows. Everything that had weight and could be moved was carried forward. There was coal on the forecastle head, coal in the foredeck up to the doors of the forecastle. Remember, the ship was now and again leaping like a terrier in the swell as the sea-anchor held her head to the sea. She began to assume a grotesque appearance as she nosed down in the waves and her stern rose in the air. Finally, the stern tube and broken shaft were right out of the water, and they could make a start on the main job.

The spare tail-shaft was lying at the bottom of the after hold, made fast by chains to the knees of the frame. The rule about carrying a spare is due to the vibration. Incessant vibration sets up what engineers call mechanical hysteresis. The molecular structure of the steel becomes strained and its inherent strength weakened. The long rest as a spare in the hold restores the molecules to normal. But the changing of the shaft is not regarded as a sea job. It is done in drydock, during a survey. Mr. McLintock proved that it could be done under very adverse circumstances. But he has had no imitators. His feat remains unique in the history of the Seven Seas and the Merchant Marine.

This was the situation at the end of July 9th, when darkness came. They were becoming accustomed to a dead ship. It is a singularly daunting experience—the sensation of a ship in midocean with the engines stopped. Every now and then the Captain and his chief engineer had glimpses of what might happen, with the stern tube open to the sea, and an Antarctic gale boiling up from Cape Horn. They had oaken hearts, but it was a grim outlook. They needed not only courage, but luck, if they were to come through. The wind that howled, the seas that slithered past their port holes as they sat in their wet, fouled clothing, eating salt meat and hard biscuits—for the cook had no time to make bread—made them think gravely of the possibilities. Would they make it? Would Mr. Ferguson prove a true prophet? They did not waste much time thinking about it, but kept on, giving each other spells at the back-breaking toil.

There was another anxiety which the Captain kept to himself. Owing to the South African war, stores had been scarce and dear in Cape Town, and he had taken a minimum that would serve for a normal eighteen-day voyage to the Plate. Now, there might be a shortage. He told the steward to take every care of what he had. He did not want to be forced to make a choice of starving on a derelict or death in open boats. He could not make the men work on short rations, but there must be no waste.

Faith in their captain upheld these men. The effect of the sea-anchor was dramatic. It did not bring peace, but it did still the mad commotion, the unbearable rolling, the endless misery of trying to rest wedged in a reeling bunk. There can be madness in watching an oil lamp rocking insanely in its gimbals, or seeing a wardroom door burst open and a derby hat bound around the cabin. The seas still slavered along the plates, still leapt on the foredeck, but all hands not at work at the moment stayed amidships. There were neither sailors nor firemen, officers or men. As in Sir Francis Drake's famous exordium,

when he hanged a mutinous Gentleman, all had to pull together. These were now just twenty men consecrated to the task of saving their ship. They probably had no time to figure out what they owed to their young commander when he ordered the flooding of the forward hold to a depth of eighteen feet. It was a horible risk, but he took it. Everything he did now was a calculated risk.

The worst remained ahead. With the broken shaft disconnected and ready to be drawn, Mr. McLintock faced the problem of getting the spare shaft into the tunnel. In a modern ship the spare shaft is located right above the running shaft, ready to be utilized at once if wanted. The one in the *Titania*, as already explained, was in the after-hold. They had no oxy-acetylene burners, no electricity. Mr. McLintock had to cut away the side of the tunnel—⅜ inch steel—with cold chisels, and then move the three-ton shaft to where it could be raised into position. A slip, and it might take charge and massacre them. In the echoing empty hold, with the slush lamps throwing great shadows, they fought furiously with the huge mass of steel. They must have resembled men who had died and gone to hell. They tore up timbers from the hold flooring to serve as levers, to make fenders, to make stools. The daylight died, but they were unaware of its passing; the hours were unregarded. The Captain, as dirty as they, crept along the tunnel from the engineroom to order them to come and eat. They would only collapse if they did not eat. The worst was yet to come.

All this time they had to keep steam, dump the ashes, put coal in the galley, pump the bilges, and watch the water-level in the boilers—the crazy, up-ended boilers. The donkey-man, firing the furnaces, would find the glowing coals falling out on his feet. As the tired, blackened men poured out of the tunnel, six firemen, two coal-passers, the messroom boy, the two junior engineers, followed by the chief—they were like nothing in the world. Most of them wore beards now and did not recognize each other. The chief glared around at the familiar scene, at the engines, at the log-board, with its record in chalk of the last day's run, revolutions per minute, total revolutions in the last completed twenty-four hours, the steam pressure, the vacuum, the "remarks." Ah, the remarks! There were no remarks. He followed the others up the ladder, exhausted.

This is only an intermission. They could not knock off. They ate ravenously, lit pipes and descended to their hell again. The tail shaft was ready to be shoved into position, but the nut was rusted and would not start. It weighed 300 pounds. They built a fire under it and around it, and they began to flog it with big hammers. It was a round piece of steel with holes in the circumference, into which would fit the "key" or wrench, for tightening it when it was screwed into place behind the propeller. There was also a pin which went through nut and shaft to lock it. That, too, was rusted. They had to work half the night on it. The bosun had opened a corner of the hatch tarpaulin to let the smoke out. They worked like demons. When they got the pin out, and the nut moving on the thread, the chief carefully oiled and examined the thread, while the bosun rigged tackle to hoist it to the deck.

Meanwhile, the sailors and the mates had begun to get the spare propeller out of the tween-deck. By the time Mr. McLintock had the tail shaft drawn (this had to be done with double chain tackle made fast to tunnel-bearing-stools) they were ready to swing out the five-ton propeller through the now open hatch. Then, beaten to their knees with toil, they slept where they lay. They waited for daylight.

It was a desperately delicate job. The ship's stern, being high, made it doubly delicate. She still had an uneasy motion, both roll and pitch, with an occasional lurch. A propellor is a difficut shape to handle at any time. It required several lines, two men at the winch and two men to tend the boom. The bosun, at the fall on the winch, took the weight, while they drew the propeller from under deck. Then, when it swung clear they had to harness it with three lines or it might come thundering across the deck and sweep them overboard. It might kill them and leap overboard. When it was finally resting on the deck and made fast—everything had to be made fast at every moment of every operation—they faced the most horrendous job of all.

The *Titania* had the usual elliptical stern, yacht-fashion, of those days; in fact, it was an unusually beautiful stern, so that her taffrail extended far out over the rudder. Under the counter, however, on either side of the rudder-post, was a large, strong, eyebolt riveted to the ship. These were used for shipping the rudder and propeller when the ship was built. Now, Mr. McLintock—who had often seen the job done at home—had to get the propeller around under the counter in what was a half-gale. The shape of a propeller is admirably designed for slipping out of its slings. The Captain had several coils of new hemp rope broken out from the bosun's store. It was for mooring the ship in Buenos Aires, but there could be no dependence on old rope now. Old hemp perishes in sea air and water. If they dropped the propeller into the sea their goose would be cooked. Every movement was now a problem, every moment a crisis.

Now the good chain strop, passing through the hole in the boss of the propeller, had to be discarded. This hole had to be left clear to fit onto the tailshaft when it appeared through the stern tube. The chief had plugged the tube with bags and wood, to keep the sea out—to keep the men in the tunnel from being completely submerged.

The *Titania* was a well-found ship of her day, and in addition to the usual hand-steering gear on the poop she had what is called a mooring-winch, to haul the stern ropes in when docking. This now came in

very useful. Now that the propeller was over the quarter one of the new ropes was led from around the boss under the stern, up through a cleat, to the mooring-winch. As the after winch paid out, this new rope drew the propeller into position. The taffrail had been removed and all was going as well as could be expected when they were electrified by a shout from the cook.

He was standing amidships by the rail near his galley and shouting "A sail! A sail!"

He was pointing aft. They had been so desperately occupied with what they were doing at the swinging propeller that they had not looked at the sea at all. Now they started at the tumbling water astern. A barquentine was standing in from the northwest. The Captain left the Chief in charge and went to the bridge. As the sailing ship came closer they saw she had flags out. They got out the Code book and looked up the name. She was the *Antigua* of Halifax, Nova Scotia, 900 tons

Captain Jackson of the *Antigua,* when a steamer was reported on the horizon, immediately made for her. He had been a long time at sea and wanted to be reported. In the days before radio, a sailing ship left port and had no means of communication with the shore until she reached her destination or her first landfall. So she always signalled the code letters of her name to a passing steamer, who reported her at the next Lloyd's station, who would cable the news to the owners. Coming closer, the *Titania* must have presented an extraordinary sight. She must have seemed in charge of lunatics who were preparing to plunge her to the bottom, head first.

Captain Jackson went back to his Code book and signalled DO YOU NEED ASSISTANCE? and waited for an answer. Meanwhile, he had noted the two black balls—which had been hidden by the funnel—and through his glass he could now see the propeller hanging under the stern. This was probably beyond anything he had ever seen in his years at sea. The flags flew out on the *Titania* and he looked up her name in the book: *Titania,* London. The flags went down and a new signal was made: I AM SENDING A BOAT.

Captain Jackson said to his first mate, "Now we shall know!" He knew steamer folk were peculiar at times, but he was curious about that propeller, hanging over one ear, so to speak.

A boat, with the *Titania's* third mate coxing, and four sailors rowing, was lowered slowly into the sea, the falls dangerously slanted owing to the ship's unusual trim. It was a ticklish operation, but most of the *Titania's* deck personnel had been in sail and knew their stuff. It was a long pull across the big seas. The *Antigua's* captain could see they had sailors on board that steamer. He prepared to receive them on the lee quarter of his ship. When the boat came alongside, the third mate—who had served his apprenticeship in sail—nimbly grabbed the rope ladder and came up hand over hand like a monkey. He then looked down to make sure his crew had the painter that had been flung to them, then shook hands with the captain, and said he had been sent to see if they had any stores they could spare. He told the Captain they had lost their propeller and were shipping a spare one. He explained about the shortage of stores. The Captain told his steward to break out some biscuit and bread and a can of preserved potatoes. This last was only used in emergencies and the Captain was willing to part with it. It was very nourishing, but nobody liked it. The third mate pointed to the sea-anchor, which he said was good. Then he helped the steward lower the stores into the boat, shook hands again, and was over the side and into the boat.

"Mind you report me," the Captain said, leaning on the rail.

"In B.A." the third mate said, "if we ever get there."

Captain Jackson watched the boat awhile and then he gave the order to square away and make sail. He saw the signal on the *Titania's* bridge: THANK YOU. He dipped his Red Ensign three times in benediction. He did not know it, but he had had a ringside seat at one of the most unusual achievements that ever took place on the high seas.

The propeller was now in an approximate position, so that they could proceed with an even more difficult and hazardous operation. They had to get it into the space between the rudder-post and the stern tube. It was growing dark again, but they could not stop now. Two buckets, with oakum and tar, were lowered over the stern, and two bosun's chairs, used for working on the masts and rigging, were brought up, and Mr. McLintock went over the stern in one of them with a set of chain-blocks on his shoulder, to hook to the big eye-bolt already mentioned. He came up and got another set of chain tackle for the other eye-bolt. Then he was lowered to the stern tube, where he attempted to grapple with the swinging propeller. To get the stern tube clear of the water the vessel had been tipped till the eight-feet mark was awash; but as her stern dipped, the water was sometimes rising to the sixteen-feet mark, and the sea boiled and swirled under her counter. He managed to lay hold of the rudder, but the ship took a dip and he went under. He was hauled up and prepared to make another try. Finally he made a connection and they could take the weight from the lines to the winch. When the two chain-tackles were drawn tight the propeller was reasonably secure, if another gale did not come up. But that was the inevitable and calculated risk. He was hauled up for the night and they took a spell.

Next morning, the Chief and bosun, who volunteered, went over the stern in bosun's chairs. The Captain, who was watching, ordered the carpenter to make another chair. When it was ready, he too went

over. He and the Chief lashed themselves to the rudder-post and waited. The ship sank, and they went under. It rose, and they began to work. The water was very cold. The counter above them would lift dizzily one moment, and dip the next to create a smother of foam in which their heads would be revealed, at the next lift, to the watchers hanging out over the quarter on both sides. Less determined men would have given up the job there and then; men with less powers of endurance could not have stood it. It was so cold that their fingers refused to grasp the colder steel of the rudder-post.

They had arranged a series of signals, with hammer blows, to the engineers in the tunnel who were working hip-deep on the tail shaft. The chief had a hammer slung on a line around his neck. For three hours the three of them tried in vain to get hold of the propeller, which was now and then banging against the ship. The plug they had fitted to the stern tube had gone. At times, the seas threatened to dash them against the propeller, but before they could get hold they were flung away again. The watchers on the poop above them, face down flat, and clutching the edge of the coaming, waiting for orders, must have thought they were gazing down into the lower circles of hell.

At last the signal came, after hours of frustration, and the half-drowned engineers in the tunnel began to haul the new tail shaft into the tube. It was a long, slow business. They had a twenty-ton jack and double chain-tackle. The jack had to be continually shifted for a new purchase, but every inch they gained cheered them. They were winning! If only the Chief got the propeller into position, the rest would be—by comparison—easy. Now the sea could no longer surge in and drown them. The bilge pumps soon left them clear of the water in the tunnel. Outside, the Chief was keeping the propeller as nearly straight as possible so that when the tapered end of the shaft appeared he would be ready. At last they heard the chief's hammer. The shaft had come through. Work fast now! The propeller was about right; work fast! They sweated and worked fast. It was four o'clock again, and darkness was falling before the shaft was in position and the chief was ready for the nut. The men in the tunnel had no idea of the time. They had to go on sweating to get the bobbin shaft into place. The Chief and his assistants, Captain and bosun, came up for a rest. The gale was increasing, the wind, laden with sleet, howled over the grey waste of foaming ridges, but they dared not stop. They had to work another hour or two by the flares before the Chief was satisfied the propeller was safe. Another day of inhuman toil.

Next morning, at daybreak, they went over again and made themselves fast to the rudder pintles. By noon they were ready to start on the nut, which was to be lowered to them. It was a cylindrical affair, not hexagonal, with holes into which the wrench fitted to turn it. The nut was 300 pounds, and the wrench was even heavier, and it took three powerful men to handle this part of the job. Great care had to be taken: the ticklish part was to get the nut started on the thread of the shaft. Some trouble was occasioned by the bosun not understanding that the thread was left-handed. You had to turn it to the left to get it started—he kept trying to turn it the conventional way at first. Finally the chief had the thread ready to go. He was able to make nearly one turn by hand, then the key or wrench, which had a hole for a line at the end of it, was lowered to them and they got it on the nut. The men above started to pull on it. It was a long job. It took six shifts of the wrench to make one turn on the nut, and twenty complete turns to get the nut hard up against the boss of the propeller. By this time the men above had the line taken to the winch to pull it tight. Human strength was no longer sufficient.

But this was not the end. The Chief had to get the nut exactly into position so that he could put the pin through the hole in the saft. It was heart-breaking. Sometimes he took half and hour to make them understand he wanted to back a sixteenth of an inch. This involved reversing the wrench. Then they would drag it too far and the whole weary business had to be gone through again. Finally he yelled "STOP HER!" He had the pin around his neck on a piece of spun yarn. It was now dark again but the pin triumphantly sank into its hole and he flogged it with his hammer.

The bosun had come into contact with one of the flares when the ship had lurched, and was badly burned. He was now hauled up, and the Captain followed. At last the Chief came up over the coaming and the Captain helped him to stand up. He moved very slowly now. It may have passed through his mind that he had won one of the most remarkable victories over the sea. His clothes were filthy; he was, like the rest of the crowd except the messroom boy, unshaven; he had been soaked through and through with sea water; he was a mass of bruises and minor cuts. He was in his twenty-fourth year and he had, against fearful odds, saved his ship. We have no hint of his thoughts. We can believe he was preoccupied with his fore hold, which had eighteen-feet of water sloshing around in it. It was a constant fear in his mind, but they had had to do it in order to get the stern high enough. The steward had coffee ready and then the Chief went down to cheer the men in the tunnel. He found them turning the main engines to bring the holes in the shaft in line so that they could bolt the flanges. They were working well, and they all knocked off for the night. The second mate, who was the navigator, had sized a clear horizon just before dark and taken a stellar observation. The *Titania* had drifted two hundred miles to the southeast.

Next morning Mr. McLintock went over again, to lock the pin in its place, and disconnect the tackle from the propeller blades. He made lines fast to the

tackle and, when the men on deck took the weight, he disconnected the hooks from the eye-bolts. Two hours sufficed to cover the work of securing the pin and removing the slings from the propeller. When he came up for the last time, he smiled. The bolts were nearly all set up on the main shaft. The donkeyman was oiling the engines. The third engineer was turning the main engines slowly, and nothing seemed amiss. Mr. McLintock came down the ladder. He had quite a beard by now, but he smiled. He told the third mate to take out the turning gear and lock it. The donkeyman was making a racket in the fireroom getting the steam up. Two firemen had been laid off to rest, to be ready for the first watch. The after-peak and ballast tanks were filled to bring the vessel to her proper trim. Gradually her stern dropped and she came on to a more even keel, but there was still the flooded hold to be pumped out. Without a doubt, as her bows rose she would fall off into the trough of the sea, in spite of the pull of the sea-anchor and the tarpaulins in the main rigging, and they might lose her yet through the mass of loose water in the half-empty hold. She must be kept head on to the seas, and the captain ordered a full head of steam.

The Captain came out of the chartroom where he had made a note of the date and stepped to the engine-room telegraph. STAND BY. There was a moment's wait, and he got an answer. Mr. McLintock was taking a turn out of his engines, to and fro, to and fro. In a moment he would venture a complete turn. He set her astern and watched for any unusual developments. Then he set her ahead very slow. Then he swung the telegraph vigorously and rang SLOW AHEAD. The answer came at once. He could feel by the vigor of the movement the Captain's state of mind. He, too, was elated.

Captain MacMillan got her on course to the West. He now felt the beat of the propeller and his heart was gay. His ship was no longer a derelict, out of control. No longer did the two black balls hang threateningly over them. The navigation lights were made ready. Next day, maybe, he could get a sight.

Meanwhile the mate took in the sea-anchor, tripping it by a line which had been attached to the crown of the kedge, and hoisting it on board. You might think they would just cut it adrift, but he wanted those oars and awning spars, the five fathoms of mooring chain and kedge anchor hanging from it, and the three-and-a-half inch wire hawser. Captain MacMillan did not believe in wasting anything. They had been six days and nights out of control. He hoped nothing more would delay them.

The steam was shut off the deck as soon as the sea-anchor flopped down and was made fast. The after hatch was battened down again, and the two tarpaulins were taken off the rigging.

It was not long before Mr. McLintock had a full head of steam. With the engines the vessel was kept head on to the seas until the flooded hold was pumped dry, and the next day, the 15th of July, she went off full speed for Buenos Aires. His only anxiety now was his boilers. He had lost some fresh water by pumping out tanks, and the density of the boiler water was rising. The First Assistant was now on watch, relieving the others. He was not communicative and nobody expressed any curiosity as to his thoughts. The effect on the crew when the engines began to turn was magical. While the work had been going on, on a dead ship, they had lost count of the days. They neither washed nor shaved. Now they came to life. She had been a log flung about on the insensate sea. Now their hearts leapt within them. They moved around smartly. They exchanged jokes. They looked over the side at their enemy and felt triumphant. They spat to leeward. They dumped their ashes with a lordly clang.

The *Titania* was one of those tramp ships of which it used to be said they were built by the mile on the North East Coast and cut off to suit the customer. It was a good joke, but a tramp is very much more than a steel girder closed at the ends. She is a complex of cunningly balanced forces. She has to run for long periods without overhaul. She has to make her charters, and she has to make money in competition against foreign ships who have no Plimsoll marks. She has no government subsidy. She is the work horse of the seas and is on her own. In those days, before radio, she could meet a storm and be lost and no one would know until after many days, she was posted missing, at Lloyds.

They arrived in the River Plate on the 21st of July, a week late, but were able to get their charter. Lloyd's Surveyor was much impressed when he heard the news of their exploit. He consented to have the tunnel bulkheads replaced at once, so they could load. He cabled Lloyds in London. He was a Scot himself and he was not very surprised that two Scots had done the job. It was common knowledge that if you give a Scot engineer a corkscrew and a ball of twine he could circumnavigate the world.

When the *Titania* reached Liverpool she was found to be as seaworthy as could be expected after a voyage to the far East and Australia. She was drydocked and the propeller was passed for another voyage. Spares were put on board, but neither Captain nor Chief Engineer wanted to contemplate another such experience.

Lloyds presented Mr. McLintock with a Citation, and their Gold Medal, for what the Army calls "devotion beyond the call of duty." Mr. Ferguson was paid off, and the Board of Trade, which carries out the duties of Her Majesty's Lords Commissioners in Council for Trade, cancelled his certificate for life. He went to sea again, in uncertificated jobs. It would be wonderful to have a transcription of his account of the voyage. He had been asked for his advice and the fruits of his experience, and it had been ignored. His unsuccessful search for justice would continue over all the Seven Seas, but we hear of him no more.

We must not be too hard on him. He had a point. Many men would have hesitated in such a crisis. What he did not know was that great achievements involve a calculated risk.

TO ROUND OUT THE STORY*

McLintock was 23 years old when he became Chief Engineer of the *Titania* and served in her for seven years, until she was sold to foreign owners. He then served with Ellerman Bucknall Lines as Chief Engineer of their passenger liners for eleven years, taking out their latest vessels in turn, the *Bulawayo, Fort Salisbury, Johannesburg* and *Kandahar,* serving six years in the latter vessel. The *Kandahar* was on the London, South Africa, India run, for the entire period of World War I from 1914 to 1918. During this time another big repair job at sea occurred in 1916, and although not comparable to the shaft and propeller job, it required a certain amount of resourcefulness for its solution.

The *Kandahar* was bound from London to Calcutta, New York and out east again. In the Mediterranean, outward bound, the high-pressure cylinder valve chest cracked about four or five miles off Algiers. Fortunately, there were no enemy submarines in the Mediterranean, and they turned around and limped into Algiers harbor, and set to work compounding the engine. The rods, *etc.* were disconnected, piston and cross head blocked and the entire job of compounding the engine took only 46 hours. The vessel then put out to sea again, compounded on the IP and LP cylinders and proceeded to Calcutta and then New York. The speed averaged only a knot less, and the fuel consumption was only slightly higher.

The vessel was equipped with a new type of superheater, Elesco, and carried over 200 degrees of superheat, over 620 degrees at the throttle, which did away with a lot of the condensation and was responsible, to a large extent, for the economy in fuel consumption. The superheater was just coming out in those days and was not so well taken care of on some ships, through lack of sufficient experience with it on the part of the engineers. When the ship arrived in New York via the Far East, a new high-pressure valve chest was waiting on the pier, and the New York Marine Superintendent remarked, possibly with his tongue in his cheek, that "it seemed a waste of time and money to change her into triple expansion again, since she had done so well compounded." From New York the vessel proceeded to the Far East again. In those days merchant ships' officers got home only every two or three years. This gave them an opportunity to find out if they still had families!

When World War I ended William McLintock retired from the sea and settled in New York, at the age of forty-one, after having served at sea for twenty-two years, eighteen of them as a Chief Engineer. He accepted the position of marine superintendent with J. F. Whitney and Company, and when they gave up shipowning he entered the employ of the Elesco Superheater Company.

In World War II, after having been retired from the sea for twenty-four years, and being now sixty-six years of age, he could not remain inactive while the country was making radio appeals to merchantmen to return to the sea. In May 1942, he returned to sea in the *Thos. McKean,* and ten days out of New York en route to Murmansk, the vessel was torpedoed and sunk. The Captain's lifeboat was never heard from again, but McLintock's boat was picked up after six days and nights. After a few days of recuperation in the hospital he could not resist going out to sea again as Chief Engineer of the *Abraham Lincoln* and seeing the war through to its conclusion.

William McLintock served at sea through the entire duration of three wars, the Boer or South African War, World War I, and World War II. He died last year, at the age of 80, in Miami, Florida, where he had taken up residence.

* The details of William McLintock's subsequent career have been provided by his son, Rear Admiral Gordon McLintock, USMS, Superintendent of the United States Merchant Marine Academy at Kings Point, New York.

ROBERT TAGGART

NOVEL MARINE PROPULSION DEVICES PART II

THE AUTHOR

who recently was the Technical Administrator of Reed Research, Inc., has just incorporated as Robert Taggart, Inc., to engage in consulting and marine research and acoustics. He received his Bachelor of Science degree in Naval Architecture and Marine Engineering from Webb Institute of Naval Architecture in 1942. He served with the Consolidated Steel Corporation, U.S. Maritime Commission, U.S. Army Transportation Corps, and the Navy Department prior to his employment with Reed Research in 1954.

EDITOR'S NOTE: Part I of this paper was published in the November 1958 issue of the JOURNAL. All of the references for both Part I and Part II will be found in this issue. This is more of Mr. Taggart's material which the author intends to revise and publish in book form.

UNUSUAL ADAPTATIONS OF THE SCREW PROPELLER

THE history of the screw propeller contains a fascinating series of deviations from the direct course of progress in its logical development. Some of these deviations are of such a character that they fall naturally into a discussion of novel marine propulsion systems.

Mr. John Taggart of Boston invented a propulsive device in 1880 labelled *Twin Gain Screws*. These screws consisted of long buoyant cylinders running parallel to the centerline of the ship port and starboard. The helical screw threads wrapped around the periphery of the cylinders increased in pitch from bow to stern, hence the name *Gain*. The cylinders were mounted in bearings set into yokes or struts fore and aft, and were rotated by means of a chain drive. Mr. Taggart claimed that a river boat fitted with these devices could be driven at a rate of 37 miles per hour. Although he proposed construction of a tug to prove his contentions, there is no record that the vessel was ever built.

At Greenpoint, Long Island a side-screw steamship was constructed in 1882 for service in Cuba. This vessel had a length of 100 feet, a beam of 32 feet, and a draft of 3 feet, with a 100-ton cargo capacity. She was designed to utilize a unique propulsion principle proposed by a Mr. Root, who expounded:

In the present method of applying the screw-propeller wheel, the maximum propelling effect has without a doubt been obtained, for it is well-known that an increase of engine power gives nothing like a proportionate effect in speed. Sixty percent of all the power is wasted somewhere, Mr. Froude calculates, and accounts for this great loss of power in the present method of stern screw-wheel propulsion in the fact that a screw wheel at the stern of a vessel draws water away from the afterbody, creates a suction, as it were, and of course, increases thereby the head resistance, such increase varying with the size of the column of water acted upon by the wheel.

It is a fact in practice that all craft propelled by a stern screw-wheel, when they reach a certain velocity settle down by the stern; and pile on the power as you may, beyond that point no more speed can be obtained. They can and do settle, however,

which fact shows clearly that a vacuum is formed when a high rate of speed is obtained, and that the screw-wheel, operating in the vacuum, becomes, more or less, a retarding instead of a propelling force, as such "minus-pressure" adds directly to the head resistance. It has lately been found in England that at high speeds the power does not follow the speed produced in a uniform ratio, as at some speeds it may vary as the cube; beyond that it drops down as low as the square of velocity. Fluid action around a vessel is something of an enigma, and the columns of water acted upon by a screw-wheel at the stern, in its reactionary thrust, is more so. The fact of the enormous waste of power in the best examples of steam screw-wheel propulsion is incontrovertible.

This partially erudite, partially uninformed exposition on resistance and propulsion theory, thrust deduction and cavitation, is reflected in Mr. Root's propeller installation. He utilized two screw propellers mounted at either end of a shaft which ran athwartships such that the plane of the propellers was parallel to the centerline plane of the vessel. These propellers were mounted slightly aft of the ship section where the parallel-sided hull started to fair down into the run. The pitch of the propellers was such that the flow of water would be directed inward toward the hull, which would be of concave curvature in that area. The inflow would then be diverted through a ninety-degree angle toward the stern. The effect on the ship was to be similar to that of converting a watermelon pit into a projectile by squeezing it between the thumb and the forefinger. Whether Mr. Root's boat ever made it to Cuba is unknown, although a propulsive efficiency of fifty-percent was claimed on trial.

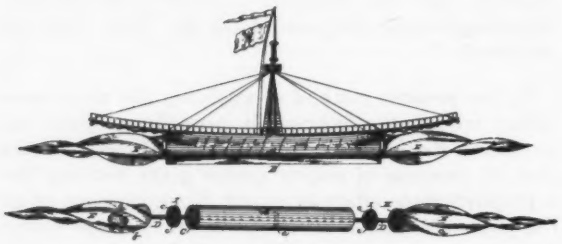

Figure 20. Marty's Screw Ship.

A bow and stern pair of buoyant screw propellers was patented by A. Marty in 1886. It is apparent from Figure 20 that Mr. Marty intended to do things in a big way. if they were to be done at all. There is a persistent rumor that it was also in 1886 that the term *screwball inventor* was coined.

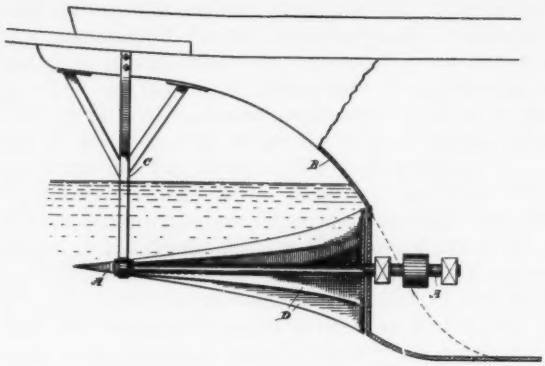

Figure 21. Stevenson's Centrifugal Auxiliary Propeller.

Robert Stevenson of San Francisco, California, patented the device shown in Figure 21 in 1889. It consisted of *radial blades or wings having the exterior edges either tapered or in straight or curved lines from front to rear and secured to a shaft projecting from the bow of the vessel, so that when driven at a high rate of speed the centrifugal action of these blades will throw the water outwardly and will produce a partial vacuum or open space in front of the bow of the vessel, into which it may be moved or forced with less expenditure of power than when the vessel is moved into water in its ordinary condition.* Stevenson intended that his device be an auxiliary propeller for the sole purpose of reducing the resistance of the ship. He suggested a screw propeller be employed at the stern for normal propulsion.

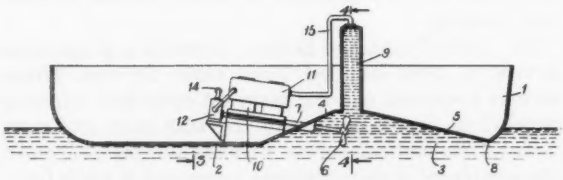

Figure 22. Fowler's Vacuum Tunnel Boat.

In 1916 Carl H. Fowler of New York City obtained a patent for a vacuum tunnel boat construction. His idea, as shown in Figure 22, was to raise artificially

a head of water over the propeller so that it would operate in solid water without cavitation. He accomplished this feat by sucking water from the top of the vertical chamber with the engine circulating water pump. Since it was necessary to cool the engine anyway, he obtained his suction free. His claim was that the pressure of the water in which the propeller operated would be equivalent to the head of water in the standpipe. It is unknown whether this dubious reasoning was ever put to a test.

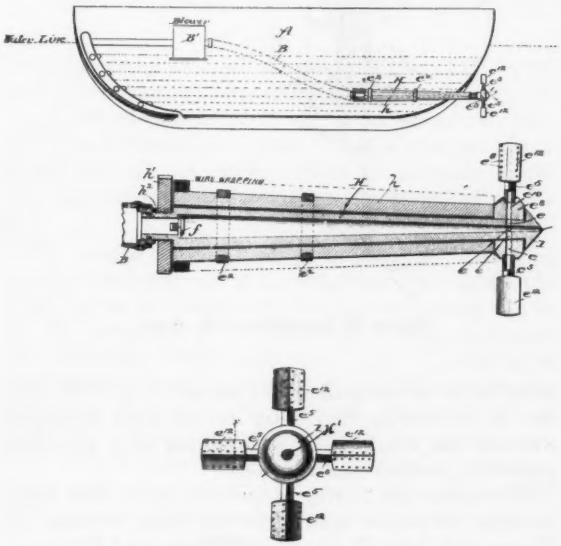

Figure 23. Walker's Pneumatic Propulsion Means.

In 1899, a patent was issued which indicated, on the part of the inventor, a real understanding of propeller cavitation. James C. Walker of Waco, Texas invented the air-emitting propeller shown in Figure 23. Air was passed down the hollow shaft and emitted through a series of holes in the propeller blades. The air thus emitted served to increase the pressure at the propeller and supplied air to fill the cavities normally created at high blade loadings. Thus, loss of thrust due to cavitation would be avoided.

An invention by August A. Rusteberg of Chicago, Illinois, in 1944, demonstrated that the old bladed-wheel propeller had not been forgotten. Rusteberg's device shown in Figure 24 had a pair of large cylindrical tunnels suspended below the hull. At either end of the tunnels were carried a pair of bladed wheels driven through a gear train. With questionable logic, Mr. Rusteberg claimed that *an important object of the invention is to provide watercraft, either of the surface-going or the submarine type, with means which utilize a greater percentage of the power output of the prime mover than has heretofore been utilized.*

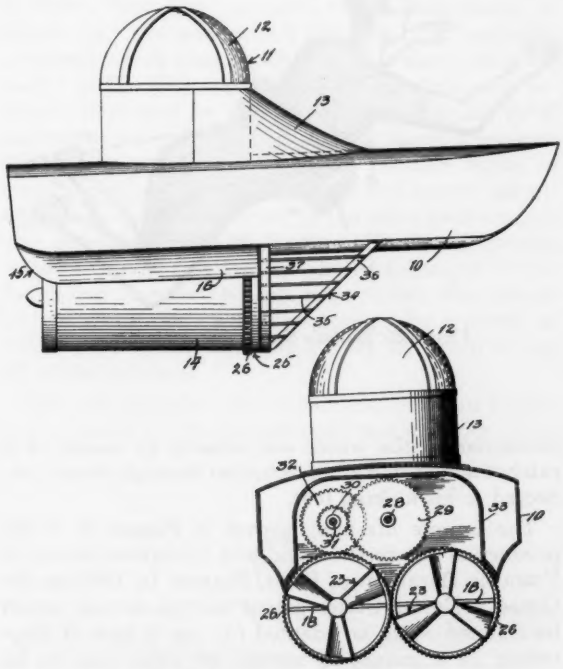

Figure 24. Rusteberg's Water Craft.

Although none of these inventions other than Walker's had any practical value, they did show some of the wide variations of mechanisms which men's minds can conceive as means of forcing marine vehicles through the water.

MECHANICAL PROPULSION OF SWIMMERS

Some of the most novel and interesting propulsive devices to aid swimmers in speeding their way through water have been patented. Most of these employ basically standard propulsive elements but the manner in which they are combined and the powering system used is generally novel and frequently amusing.

Edmond R. Mallet of San Francisco, California believed that the swimmers of the day could attain a greater speed of advance by the addition of a small mechanical aid. In 1892 he patented the device shown in Figure 25. The Archimedian screw strapped to the

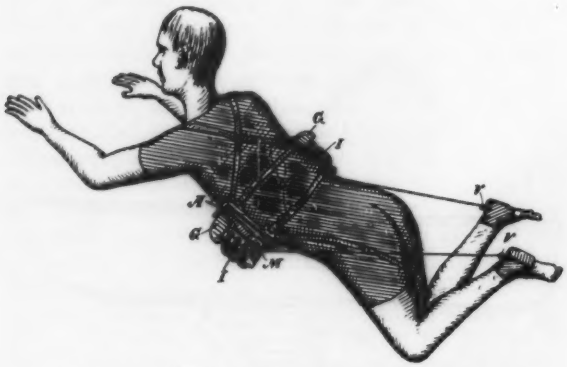

Figure 25. Mallet's Swimming Apparatus.

gentleman in the water was rotated by means of a ratchet and spring affair actuated through wires connected to his kicking feet.

The unique life-buoy shown in Figure 26 is the product of the fertile mind and inventive genius of Francois Barathon of Paris, France. In 1895 he obtained a United States patent on this device, which he claimed could be adapted for use in case of shipwreck as a means of saving life. The soul to be saved was to climb aboard this contrivance, blow up the buoyant cushion by suitable means, strap himself aboard (not forgetting to buckle his feet to the pedals), and then pedal away from his sinking ship. Once safely launched he must hoist his commission pennant and, if the wind was favorable, rig his square sail. Should he desire to signal a vessel toward which he was heading, he need only reef his sail and tap out a message on the light provided just forward of his nose. If he desired to see where he was going, reefing of the sail was also helpful. And if, by some misfortune, his cushion should spring a leak he could quickly clutch in his vertical propeller and take off like a helicopter.

George B. Shepherd of Grayson, Kentucky also

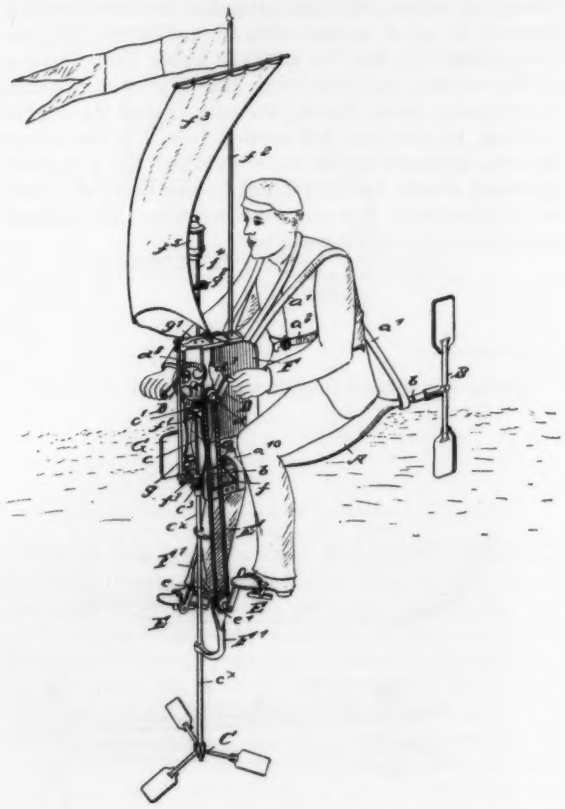

Figure 26. Barathon's Life Buoy.

patented a self-propelled life preserver in 1898. Figure 27 illustrates this snug device fully equipped with all the comforts of a habitable ship including propeller, rudder, and snorkel.

The rising popularity of swimming in 1910 again brought inventive genius to the fore. William H. Young and Oscar B. Lyon, of Modesta and Maricopa, California, got together in that year on another

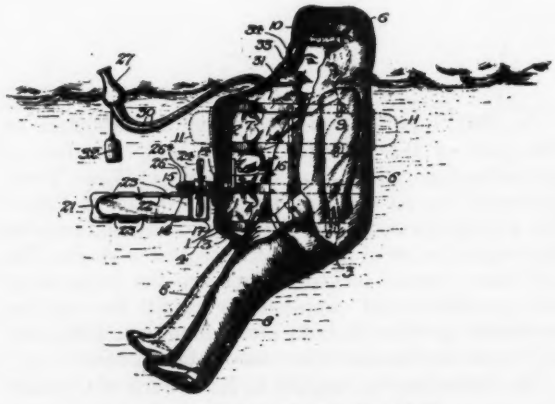

Figure 27. Shepherd's Life Preserver.

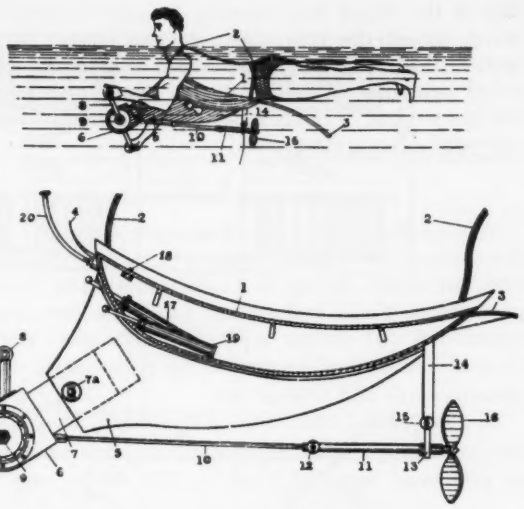

Figure 28. Lyon and Young's Swimming Machine.

swimmer-assist device. Their invention, Figure 28, *relates to improvements in means for navigating the water and particularly to a means for permitting persons who are unable to swim to readily propel themselves through the water, either for pleasure or for necessity, as for instance, when shipwrecked or the like.*

This device contained several unique features. The buoyant chamber could be regulated for any weight of swimmer by means of the suction pump, *17*, or the discharge pump, *18*. Likewise the gear box support, propeller shaft, and strut were adjustable to accommodate varying lengths of arms. *A rearwardly projecting guard, 3,* was conveniently provided *to protect the body from injury from the propeller or other things.* And if the swimmer should inconveniently submerge he could inhale air through tube *20* which was connected to his buoyant compartment.

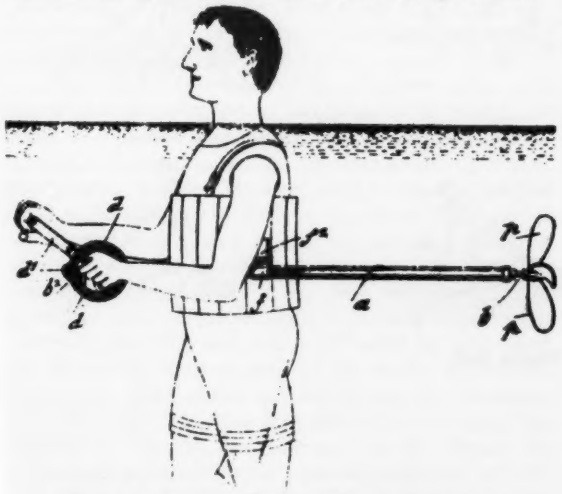

Figure 29. Krohn's Swimmer Propelling Device.

Figure 30. Krohn's Outboard Motor.

As an *improved propelling device which is to be used for sporting purposes or when bathing for moving the body through the water,* Christian Krohn of New York City invented the device shown in Figure 29. It is understood that the only limitation on speed which was imposed by this device was the height of the bow wave; once Mr. Krohn's nose became submerged he was forced to reduce his RPM and cut down from flank to cruising speed. However, Mr. Krohn soon tired of this particular brand of aquatic pastime, grew a mustache and goatee, adopted a monocle, and reverted to the more gentlemanly and dignified sport of boating. He found rowing rather tiresome and also developed a distinct dislike for gazing at where he had been rather than where he was going. As a result he applied for a patent in 1911 for the device shown in Figure 30, which solved all of his problems.

The gear rigged to the dapper gentleman in Figure 31 resulted from the collaboration of Alexander Patus

Figure 31. Patus and Csicsmann's Mechanical Swimming Device.

and Anthony Csicsmann of South Bend, Indiana, in 1914. The swimmer is supported by fore and aft buoyant floats. His propelling mechanism is none other than the old hinged duck-foot which Lord Stanhope tried in the 1790's. As the handle is moved fore and aft the boards alternately open and close generating a propulsive force on the aftward stroke and slipping through the water with a minimum of resistance on the forward stroke. Although the moments generated might prove to engender some slight problems in dynamic stability, there is little doubt that the gentleman could probably propel himself without so much as a drop of water disturbing the careful grooming of his mustache.

A very interesting form of undulating propulsion was suggested by Jasper Whiting of Boston, Massachusetts in 1940. As shown in Figure 32, this consisted of a raft made of hinged boards which by proper operations could be made to undulate along the surface of the water thus causing the raft to move forward. Of all the propulsion devices shown in this section this is the only one which employs a really novel principle. Whether it was ever successful is not known but to its inventor should go credit for an extremely fascinating idea.

ROLLING OVER THE WAVES

Toward the close of the nineteenth century a sudden interest developed in water craft which employed buoyant wheels driven in a rotary motion to provide propulsion. Such techniques had been previously mentioned but within a single thirty year period several varieties of experimental roller ships were actually built and tried at sea.

In 1868 Elisha Matteson of Brooklyn, New York opened this era with an application for a patent on an improved buoyant propeller. His device was the

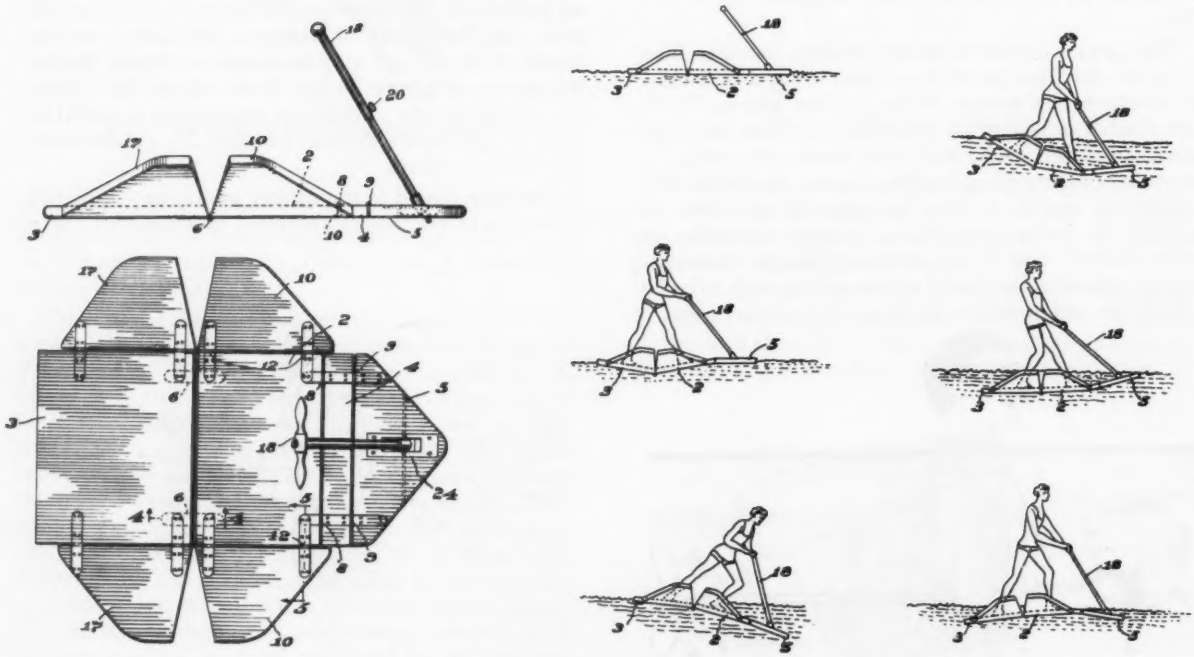

Figure 32. Whiting's Hinged Raft.

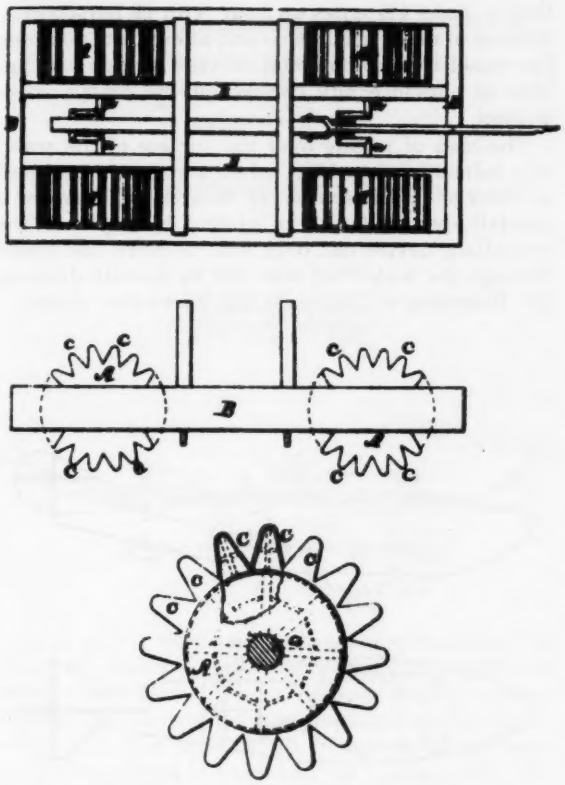

Figure 33. Matteson's Buoyant Propeller.

toothed buoyant wheel shown in Figure 33. Driven by a suitable mechanism it was anticipated that a craft fitted with these devices would carry its passengers across the water with no more difficulty than would be encountered in the operation of a hand-truck on a railroad track.

Robert M. Fryer of San Francisco, California experimented for about twelve years with the Fryer Buoyant Propeller. He first made a small model of his device which consisted of three hollow, spherical, copper globes mounted in bearings in a triangular frame. The globes were about twelve inches in diameter and each contained a spring mechanism by which they could be rotated. He next built a steam propelled model with globes six feet in diameter. This model was named *Alice* and called, by some, a floating velocipede. Fryer conducted tests on *Alice* in the Harlem River in New York. She was said to be extremely maneuverable, rolled on the water with practically no slip, and was unaffected by wind and tide. After his experiments in the water he moved Alice on dry land, under her own power, to Hastings-on-the-Hudson. He also had plans for running his amphibious vehicle on railroad tracks. Figure 34 shows excerpts from Fryer's patent obtained in 1880.

On 19 August 1896, at the Cail dockyards in St. Denis, France, the Bazin roller ship was launched. This ship, named the *Ernest-Bazin,* was about 120 feet long and 40 feet wide. Its hull consisted of a rectangular steel girder structure which was supported on the axles of three pairs of huge cylindrical rollers; the rollers were 39 feet in diameter and about 12 feet thick. The vessel displaced 280 tons which submerged the rollers to a depth of about 10 feet. The primary propulsion was delivered by a screw propeller mounted between the pairs of rollers and driven by a 550 horsepower engine. Each pair of rollers was to be driven at high speed, presumably at a peripheral speed equal to the speed of the vessel through the water, by 50 horsepower engines giving a total power of 700 horses. It was claimed that his vessel had great stability. It crossed the English Channel at a speed of 7 knots, and made a tour of the east coast of England. Bazin claimed that a trans-atlantic steamer built on this principle could make 32 knots with a power of 10,000 horses. The low trial speed of the ship, Bazin felt, was due to the inability of the motors to drive the rollers at a high enough speed. Contemporary articles concur in this conclusion.

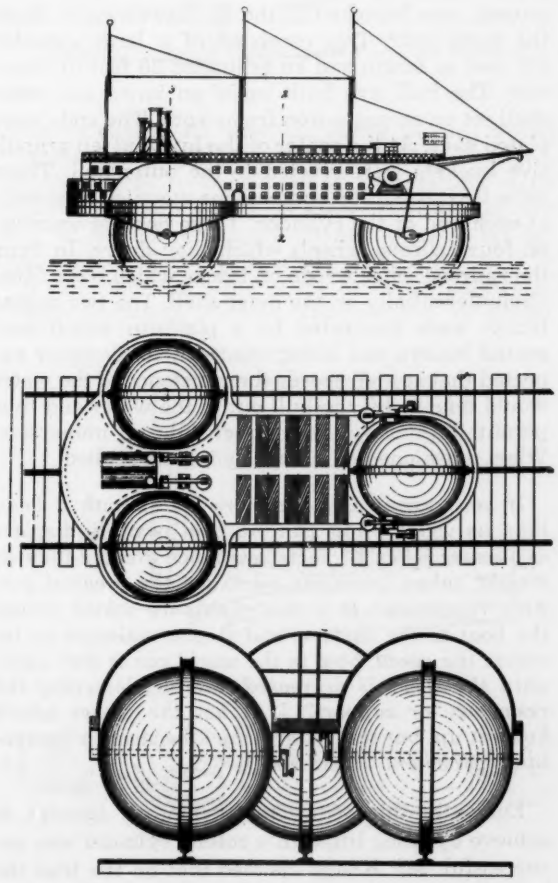

Figure 34. Fryer's Buoyant Propeller Ship.

Peter Bleckman built another form of roller boat in 1898. It consisted of a cylindrical barrel with a buoyant shell about 10 feet in diameter and 12 feet in length on which was supported a box-like frame. Around the circumference of the barrel was fitted a pair of tracks between which were a series of shallow paddles. The box frame hung on the axles of rollers riding on the tracks at the top of the barrel. Platforms were provided on the outside of the frame for the crew to stand on and quarters were provided inside the barrel but structurally attached to the frame. Rotation was imparted to the barrel through a pair of hand-operated cranks on the frame turning internal spur gears which drove a ring gear attached to the barrel. Bleckman and his young son went to sea in this contrivance sailing from Bar Harbor, Maine. Under the joint action of the hand cranks and a favorable wind they went 15 miles out to sea at a rate of 6 miles an hour. Finding the wind to be his master, Bleckman hailed the passing freighter *Pentagoet* bound for New York, and was taken aboard. He persuaded the crew to take the barrel in tow but after the hawser parted, the barrel was cast adrift despite his pleas.

The Knapp roller boat, a somewhat more ambitious project, was launched in the St. Lawrence in about the same year. This consisted of a large cylinder 125 feet in length and an estimated 20 feet in diameter. The hull was built up of an inner and outer shell set on an angle-iron framework. The ends were plated over. At the center of the hull sixteen propulsive buckets were riveted to the outershell. There were two propulsion engines, one mounted internally at each end of the cylinder. These engines were set on four railroad wheels which they drove. In turn, the railroad wheels rode on tracks which were fitted circumferentially on the inner shell. The two engine trucks were connected by a platform which supported boilers and living quarters. Its designer expected that at high speeds the resistance of the water would tend to lift the hull out of the water and thus permit it to travel with practically no immersion. When questioned on his reasoning, he replied:

If you cannot displace more water with a body than its weight, how can my boat possibly displace any water when it meets resistance greater than its weight, taken broadside on to get the greatest possible resistance? It is this resistance which brings the boat to the surface, and if you maintain or increase the speed, how in the world can it sink again until the speed is decreased, thereby lessening the resistance or support? It is not the power which holds it up, but the water, which becomes a "granolithic pavement," so to speak.

Evidently this somewhat premature attempt to achieve dynamic lift with a rolling cylinder was unsuccessful. Mr. Knapp claimed that on the trial the boat displaced 100 tons and drew 3 feet of water and that it made 4½ miles an hour with 15 horsepower. In spite of many arguments and attempts to publicize his vessel as a commercial success, Knapp was unable to convince any backers of the craft's possibilities.

The idea of rolling over the surface of the water was reinstituted in 1929, when a patent was issued to George G. Kisevalter of New York City for a specially-powered type of gliding hydroplane. The propelling device not only was to drive the vessel through the water but was also to provide dynamic lift. Referring to Figure 35, Mr. Kisevalter stated:

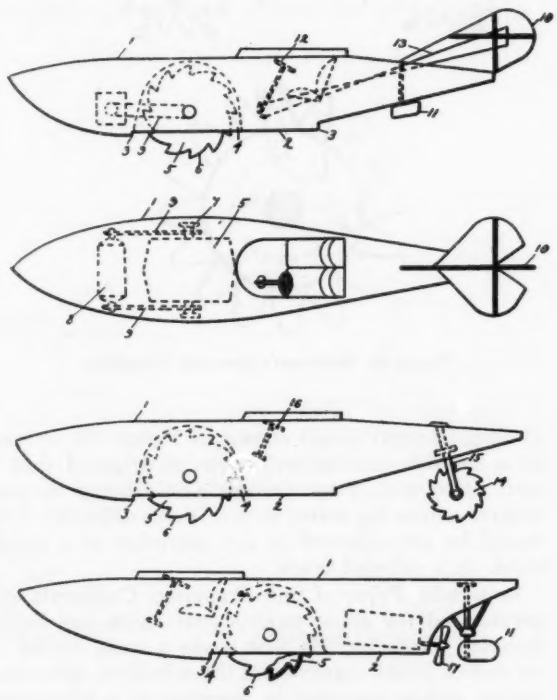

Figure 35. Kisevalter's Spinning Wheel.

A large proportion of the power in ordinary boats is used for overcoming frictional resistance of water. This resistance is proportional to the submerged surface and in hydroplanes it is greatly reduced at high speeds due to the special design of the hull enabling it to rise above the surface of the water.

In order to obtain the same result also at lower speeds I am using in my boat a special propelling device which lifts the forward portion of the boat out of the water. This propelling device consists of

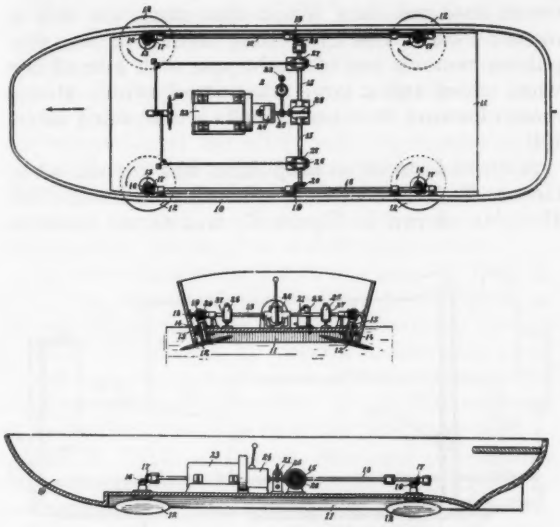

Figure 36. Weir's Spinning Discs.

a large paddle wheel extending across the hull of the boat and provided with specially shaped paddles or vanes which partially lift and partly propel the boat. Similar wheels may be also employed as gliding devices to enable the boat to rise when an ordinary propelling device is used, such as a screw propeller.

Another wheel type propulsion system was patented by Max W. Weir of Newark, New Jersey in 1929. As shown in Figure 36, the invention *comprehends a means for effecting the propulsion of a boat, hydroplane, or other watercraft which permits of their navigation in shallow water, or in water containing weeds, grasses, or other growths which tend to foul the usual type of propellers.* Weir's rotating discs were inclined in such a manner that less than half of the disc area was exposed to the water. This was intended to give the vessel a forward thrust due to the reaction of the frictional forces generated between the discs and the water.

All of these roller boats generated a great deal of public enthusiasm in their day. Unfortunately for their inventors, most of the craft displayed a fundamental lack of understanding of hydrodynamic principles. However, to the credit of these inventors is their demonstrated courage in risking their capital and often their lives in support of their contentions. It is this courage and fortitude which has done so much to advance the science and art of marine propulsion.

GAS JET PROPULSION

The idea of propelling ships by means of gaseous jets had often been advanced. Many mechanisms have been tried and usually found wanting. Some of these mechanisms are reasonable in principle, others appear somewhat ridiculous. Yet, again, gaseous emission does generate a force and therefore has the potential value of being a propulsive device.

In 1884 Alfred Leon Segond of Paris, France obtained a United States patent for a propulsion scheme to drive a ship by centrifugal force. Referring to Figure 37, a steam injector, I, was to force water through the open tube, ADCB. The flowing water would be forced around a circular path thus being

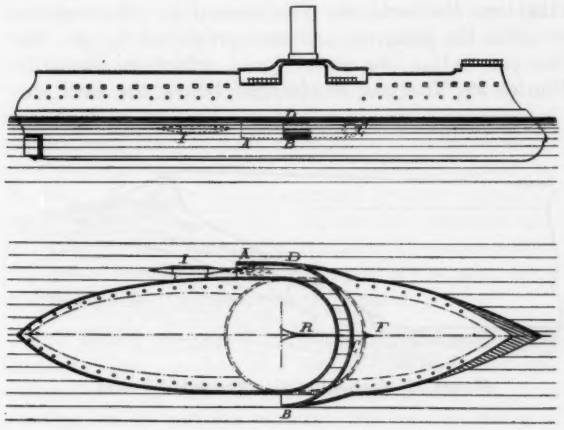

Figure 37. Segond's Centrifugally Propelled Vessel.

made to change its direction which in turn would create a centrifugal force, R, which would then propel the vessel forward. Although admitting some slight acquaintance with Newton's third law of motion, M. Segond obviously ignored some of the actions and reactions which would take place.

A forerunner of some of the modern underwater missile propulsion devices was patented by Ernest

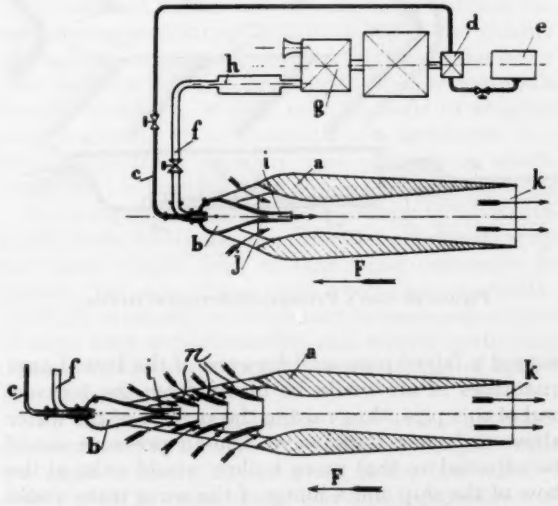

Figure 38. Morize's Jet Propulsion Device.

Morize of Boulogne-Sur-Seine, France, in 1921. This device, shown in Figure 38, operated on a liquid fuel mixed with oxygen in the combustion chamber, *b*. The high-velocity gas exiting from the combustion chamber caused a low pressure in the nozzle throat which sucked the water through the inlet annulus. The kinetic energy in the gas was thus imparted to the liquid which then exhausted at reduced pressure through the flaring after section of the main nozzle.

Henri Arnold Johannes de Bijll Nachenius of Haarlem, Netherlands, rejuvenated an old invention in 1922. He patented a *vessel propelled by gas discharged below the water level*, which is shown in Figure 39. The gas, discharged below the keel was

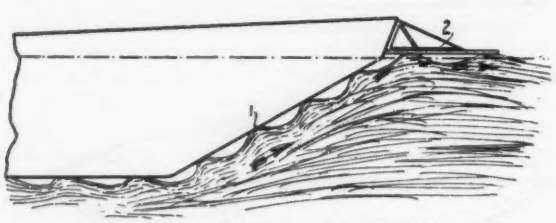

Figure 39. Nachenius' Gas Propelled Vessel.

to bubble up along the sloping after rake end of the vessel, thus accelerating the mass of liquid up the slope. One component of the resultant force would then be in a forward direction in such a manner that the boat would be propelled forward.

A method and means of propelling ships was patented by Frazer W. Gay of Newark, New Jersey in 1931. As shown in Figure 40, Mr. Gay planned to

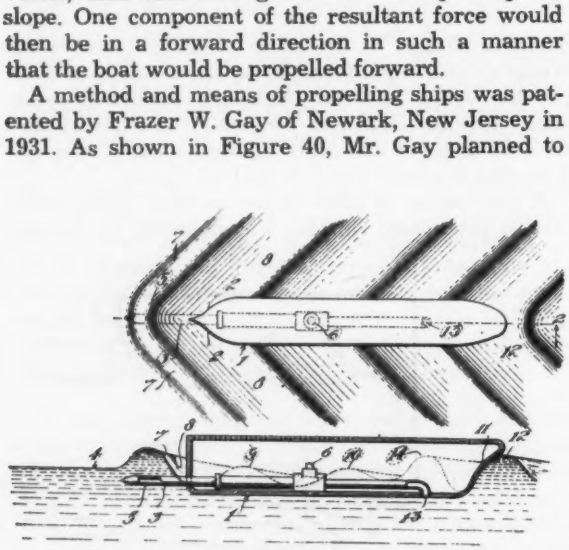

Figure 40. Gay's Pressure Differential Device.

extend a faired pipe well forward of the bow. Large quantities of air would be blown from the forward end of this pipe, thus raising the surface of the water above to form a large wave. The air pressure would be adjusted so that wave hollow would exist at the bow of the ship and a hump of the wave train would be set up at the stern. The pressure difference between bow and stern would then cause the ship to move forward. This interesting method of ship propulsion reminds one of the bicycle with a small forward wheel and a large after wheel, which always moves forward because it thinks it is running downhill.

A novel form of jet propulsion was introduced by George S. Nelson of Salt Lake City, Utah in 1937. His idea, shown in Figure 41, was to use steam to

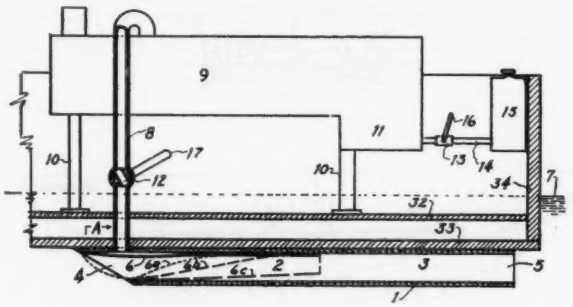

Figure 41. Nelson's Diaphragm Propulsion.

expand a specially-shaped diaphragm, *6*, in a pipe, *3*, which extended along the keel of the ship. In the suction position, the diaphragm would nest against the upper inner surface of the pipe. The diaphragm would then be forced by steam into the position, *6a*, which would close off the entrance, *4*, of the pipe. Successive expanding of the diaphragm to positions *6b* and *6c* would force the water out of the after end of the pipe, thus propelling the vessel.

Another propelling device utilizing a high rate of

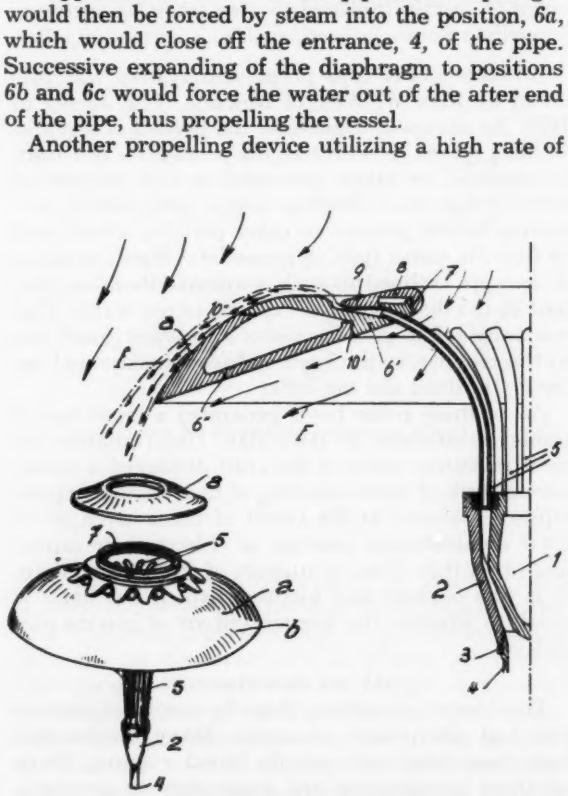

Figure 42. Coanda's Jet Umbrella.

gas flow was patented in 1938 by Henri Coanda of Clichy, France. As shown in Figure 42, a high-velocity gas flow was ejected through a series of holes on the forward face of the umbrella-like propeller, which would then cling to the umbrella surface separating at the after end. The separation of the gas flow would cause a low pressure to develop, thus pullling the fluid in which the propeller was immersed through the forward suction nozzle and discharging it out the after end of the umbrella.

It is interesting to note that this same M. Coanda enjoys the reputation of being the first to fly a jet aircraft. While working on a jet propulsion scheme for airborne vehicles, M. Coanda accidentally lit off the jet and was carried some distance through the air. The resultant destruction of his craft enforced his retirement from this new and promising field.

John H. Davis of Detroit, Michigan patented an air-pressure differential creating device in 1949. The general characteristics and potential use of the device are shown in Figure 43. Of his invention Mr. Davis says:

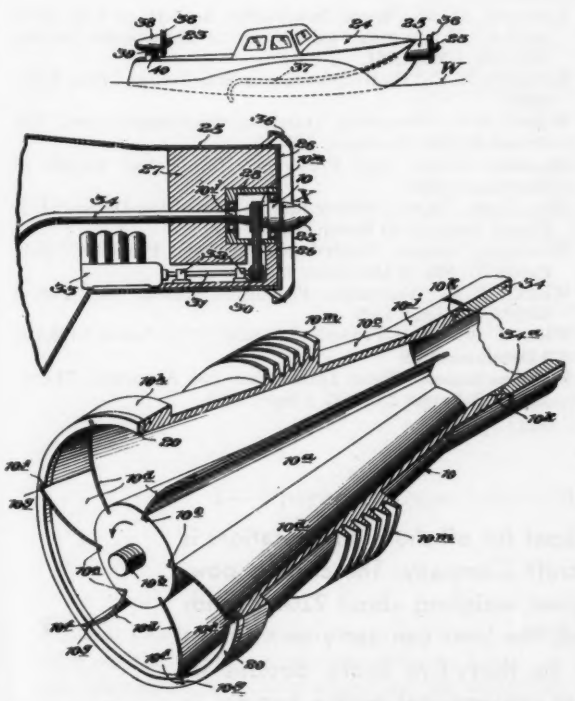

Figure 43. Davis' Air Pressure Differential Creating Device.

This invention is a novel device for creating air-pressure differentials, and the principal object thereof is to provide a unit, which may be self-contained, having means for centrifugally producing a radiating spray or film of fluid across one face of the unit in such manner that the film will reduce atmospheric air pressure upon said face, whereby atmospheric pressure acting upon the remaining surfaces of the device will move or tend to move the device into or toward the area of reduced pressure with tremendous force, thereby providing a device which may be used for lifting or propelling various articles or the like in any desired direction, horizontally, angularly, or vertically, the unit requiring a relatively small power input in order to create the above-mentioned fluid spray or film, and being very much more efficient than other lifting, pulling, or pushing devices at present known.

A further object of the invention is to provide a modification of a device of the above type adapted particularly for use as a propulsion means for movable objects such as ships, automobiles, airplanes, or the like, the device being adapted to exert a pull or push thereon to form an effective air pressure differential propelling means, thereby dispensing with the usual engine, motor or propelling means, with which same are customarily equipped.

The water is pulled into the centrifugal pump through pipe, *34*, then the water film radiates centrifugally from the slot, *X*, across plate, *26*, thus causing air to rush in through the bow nozzle and pass under ring, *36*, which sucks the boat forward.

Toward the close of the first half of the twentieth century, jet propulsion seemed to be in the forefront of inventive minds. Patents for air jets, water jets, and chemical propulsion systems have appeared in increasing numbers. The most outstanding feature of this fifty-year period, in spite of occasional deviations, seems to be a gradual transition from propulsive oddities to the scientific application of fundamental physical phenomena to the improvement of ship propulsion.

CONCLUSIONS

Throughout the history of marine propulsion developments a continual improvement in the quality of the ideas advanced is obvious, in spite of the many side issues which are presented. As new materials become available, and as new methods of shaping and machining these materials are developed, the inventor is freed of many past restrictions which might tend to hold his imagination in check.

As in all collections of the products of inventive minds, both the bizarre and the archaic mingle with the ideas which lead toward valid advances in science. Yet, even those ideas which may be fundamentally unsound, or which may be mere repetitions of ideas long since discarded, still show a continuing interest in the important engineering field of better propulsion for ships.

The intense interest in this field which has been demonstrated by inventors in the past, coupled with the rapid technological progress of the last two decades, gives promise of the continued generation of new ideas for marine propulsion.

ACKNOWLEDGEMENTS

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A high-speed, gas turbine powered boat for off-shore oil operations is being demonstrated by the Solar Aircraft Company. The craft is powered by two 500 HP Solar Jupiter engines, weighing about 2200 pounds each. Having a length of fifty-five feet, the boat can carry as many as twenty-five passengers at speeds up to thirty-five knots. Besides its weight per horsepower superiority over conventional marine engines in this size range, the gas turbine drive shows a remarkable freedom from vibration. Acceleration measurements indicate a capability of accelerating from a dead stop to full speed in twelve seconds.

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November, 1958

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

SYMPOSIUM ON GAS TURBINE SEA EXPERIENCE

ACKNOWLEDGEMENT

The Marine Committee (under the chairmanship of Captain Ivan Monk, USN, Director of the Machinery Division, Bureau of Ships) of the Gas Turbine Power Division, American Society of Mechanical Engineer, has conducted an open meeting on operating experience with gas turbines at sea. This technical session was held on December 2, 1958, during the Annual Meeting of ASME in New York, New York. Dr. Lester M. Goldsmith, Consulting Engineer, served as chairman and Mr. John W. Sawyer, Head Gas Turbine Engineer, Internal Combustion and Gas Turbine Engines Branch, Bureau of Ships, was vice-chairman for the symposium. The three papers presented at this meeting, along with discussions, are reprinted herein. The Gas Turbine Power Division of ASME provided transcripts of the papers and discussions for the purpose of this reprint.

Commander R. G. Mills, USN, is Head of the Internal Combustion and Gas Turbine Engines Branch, Bureau of Ships. Mr. Robert L. Jackson is Manager, Proposition, Requisition and Advanced Engineering, General Electric Company, Schenectady, N. Y. Mr. P. A. Pitt is Chief Engineer, Turbine and Controls Engineering, Solar Aircraft Company, San Diego, California; Mr. P. G. Carlson is Chief Project Engineer, Development, Turbine and Controls Engineering, Solar Aircraft Company.

I—Operating Experience with U. S. Navy Gas Turbines at Sea

By COMMANDER ROBERT G. MILLS, USN

A naval gas turbine installation, to be successful, must meet the following requirements:

(a) Maximum reliability under all operating conditions.
(b) Minimum maintenance requirements.
(c) Ease and simplicity of operation.
(d) Low space and weight requirements.
(e) Good fuel economy.
(f) Reasonable initial cost.

The ability of a given prime mover to meet the last four criteria can largely be established on the drawing board, the engine test stand, and initial ship's trials. Ability to fulfill the most vital requirements—maximum reliability and minimum maintenance—can be established only by extended service at sea.

In ten years of seagoing experience, the gas turbine has firmly established its ability to meet these exacting requirements. It has been a difficult and expensive task. The investment has proved sound, however. A number of installations have been highly successful; and the gas turbine now competes on an equal footing with the diesel engine and the steam turbine. Proved engines that have met the all important test of reliability at sea are now installed wherever their use

will result in markedly improved ship's characteristics, or lower overall shipbuilding costs.

U. S. Navy interest in the gas turbine for shipboard use dates back to World War II. Initial interest led to the design and purchase of the experimental 3500 SHP Allis Chalmers plant, which was extensively tested at the U.S. Naval Engineering Experiment Station in Annapolis from 1944 to 1949. This was followed by several contracts for relatively large main propulsion plants for naval ships, utilizing open, semi-closed and closed cycles; however, none of these large plants reached the ship installation stage. The first actual U.S. Navy ship installation was a small light auxiliary power unit—a 400 HP Solar T-400 turbine driving a 250 KW 400 cycle AC emergency generator set in USS *Timmerman*

This ship was an experimental destroyer given over entirely to bold advances in the design of warship machinery. The gas turbine, in common with much of the rest of the ship's machinery, was beset with a series of difficulties and casualties. Starting difficulties were encountered. The exhaust ducting and muffler were improperly mounted, and these subjected the turbine exhaust scroll to excessive stresses from thermal expansion. Compartment cooling fans were frequently inoperable; and the gas turbine was forced to operate in an abnormally high ambient temperature. Finally, some metal shavings were accidentally inducted into the compressor, and the engine was wrecked. It was replaced with a newer Solar engine (the 500 HP T-520); the exhaust ducting was redesigned; and the gas turbine emergency generator operated satisfactorily and reliably throughout the life of the ship. The unit is still in operation furnishing 400 cycle power for a special project ashore.

From this single experimental installation ten years ago, the gas turbine has now been installed in nearly 200 naval ships and boats—343 engines for a total of over 55,000 horsepower, with accumulated operating experience of about 85,000 hours. Significantly, all of these units have been relatively small, light weight gas turbines—much more closely allied to the aircraft turbine than to the heavy industrial type. Almost without exception, however, they are marine turbines, by design and by operational evaluation.

Due to their light weight and sparing use of magnetic materials, gas turbines have found their greatest application in the U. S. Navy in minecraft. The onset of the Korean War necessitated an urgent shipbuilding program of a fleet of various sizes of minesweepers, mostly wooden hulled. These minesweepers had to contain the very minimum of magnetic materials, which would cause actuation of the highly sensitive magnetic mines being encountered. The first gas turbine application was in the MSB class of minesweepers, which were designed for transportation aboard attack cargo ships. These MSB's were severely weight limited, since the lifting weight of each boat had to be within the capacity of the ship's cargo booms. Primarily because of this weight limitation, it was decided to use gas turbines to power the MSB's minesweeping generators. Each boat carries two 200 KW generators, each driven by a pair of 160 HP Boeing 502-6 gas turbines. 184 of these turbines installed in 46 boats, have now accumulated a total of 74,000 hours of operation.

These were the first marine gas turbines ever built in production quantities; and the urgency of war did not allow extensive simulated service testing ashore prior to installation aboard ship. In spite of a number of early difficulties, however, these gas turbines have been performing a vital job that no other type of prime mover could accomplish within the required limitations on weight and magnetic materials.

A rash of turbine blade failures was experienced during early operations, although no catastropic engine failures occurred from this cause. Blade failures were due partly to fatigue, and partly to the impingement on the blading of hard carbon particles from the combustors. Some combustion improvements were effected; and new blades with a 0.6 inch in lieu of a 0.5 inch blade chord were designed and installed. This remedy proved fully effective.

A number of failures of the starting motor also occurred. Heat from the gas turbine caused excessive temperatures in the externally lubricated starter bearings. Air cooling, a heat shield, and sealed bearings proved effective remedies.

Each pair of gas turbines is connected through overrunning clutches to a combining reduction gear, which drives the generator. Sticky clutches have resulted in a number of engine casualties. A new design of clutch is now being retrofitted into fleet engines, after extensive testing ashore; and all reports to date are favorable. Various other casualties to the combining reduction gear necessitated a re-design of this unit.

Current problems are small—micro-switches and thermocouples fail too often; and combustion, although satisfactory, could be improved. Although relatively of lesser importance than casualties to the basic engine, mal-operation of these items could force engine shut-downs that would prove exceedingly dangerous during wartime operations. Continuing efforts are being made to improve the life and reliability of these components.

The success of the MSB gas turbines led to their application to a still smaller minesweeping craft—the 36′ minesweeping launch (MSL). High power in a small light package, and very low magnetic signature were again prime considerations. The improved 160 HP Boeing 502-8C was used for prototype evaluation in four boats; and a still further improved 220 HP Boeing 502-10C was installed in 26 later boats (Figure 1). Each boat carries one gas turbine for propulsion, and another engine of the same type as prime mover for a 100 KW minesweeping generator (Figure 2).

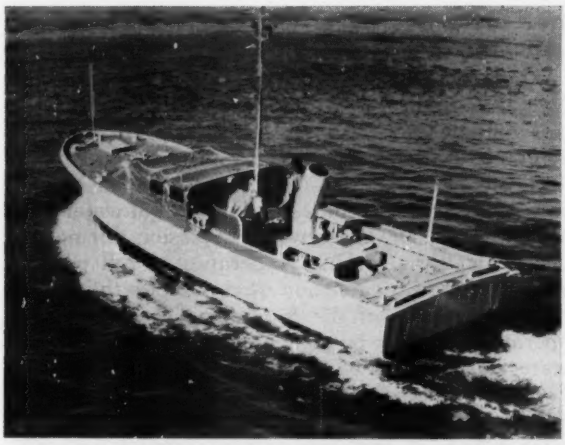


Figure 1—Minesweeping launch (MSL) powered by 220 HP Boeing gas turbine.

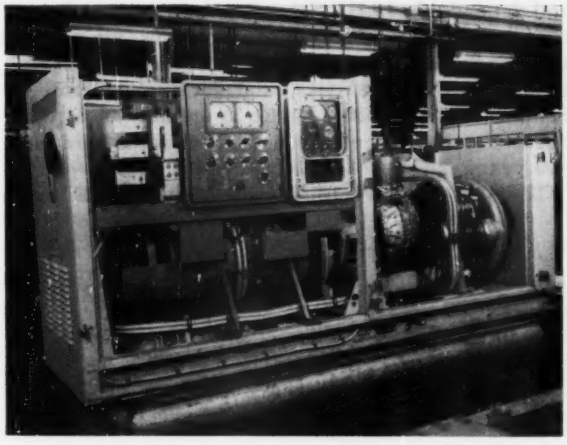


Figure 2—Minesweeping Generator set for MSL.

Operating difficulties were experienced in the prototype installations with clutches and with salt water corrosion of the anodized aluminum reverse gear sumps. Both were readily remedied.

The 220 HP 502-10C engines have also had their problems during shakedown operations. A number of blade failures have been experienced on the inducers of the centrifugal compressors. The original forged and machined inducers have been replaced with heavier-bladed precision castings, which have proved satisfactory on most installations. Slippage of a friction fit between the shaft and the second mesh pinion of the reduction gear was also experienced on some engines; but this defect was remedied before the boats were fully operational. The U.S. Naval Engineering Experiment Station at Annapolis conducted extensive tests of a complete turbo-generator package under a variety of simulated service conditions. Rapid cycling of the engine from no load to full load led to some failures that had not been experienced under thousands of hours of normal test stand operation. Inducer blade failures were accelerated; tolerances on a square shank drive for the lube oil pump proved to be too loose; large changes in internal pressures caused excessive oil consumption under extreme load conditions. These operations were severe demands upon the engine—demands that other types of prime movers could not meet with five times the weight of engine. But they do point up the great value of simulated service testing under conditions that approximate as closely as possible the environment that will be encountered at sea. Weak points were discovered and remedies devised prior to the occurrence of casualties at sea. Engine modifications were scheduled to be accomplished on operational engines during routine inspection periods, with consequent savings in monetary costs, and time of operating personnel who were busily preparing the boats for transport to distant operating areas.

The 220 HP Boeing 502-10C engine was also installed in three small landing craft (LCVP) for evaluation purposes, following a strictly experimental installation of the earlier 502-8 engine in a similar landing craft at the U. S. Naval Engineering Experiment Station. Unfortunately, evaluation began before the various remedies mentioned above had been devised and installed; and the operational tests have been temporarily discontinued.

Several highly successful installations of the 500 HP Solar T-520 and T-522 engine have been made. The installation in the 40′ *Solar Meteor* is described in the companion paper by Mr. Carlson. This was followed by a similar installation in a 40′ landing craft (LCPL). Both of these boats have been eminently successful, and are being followed by similar installations in eight more LCPLs.

Five of these engines have been used for generator drives—four as prime movers for 200 KW minesweeping generators, and one as an emergency 300 KW generating set on the Navy's first guided missile destroyer—USS *Gyatt*.

The successful results of a 1500 hour test on the minesweeper generators were reported in ASME paper 57-F21 by Pickel, Blackwood and Henry. Subsequent operations have been almost entirely trouble-free.

USS *Gyatt* is a World War II destroyer which was converted in part to guided missile armament. Additional emergency generator power was required; and only the gas turbine could deliver the requisite power within the somewhat tight weight and space limitations. A ten second start was specified; that is, within ten seconds after failure of regular ship's power, the cold gas turbine generator set must be started and delivering full power to the ship's electrical system.

Starting difficulties were initially experienced due to improper hook-up to ship's high pressure air supply, defective engine fuel scheduling and faulty combustion starter. Difficulties were satisfactorily corrected by Solar and the conversion shipyard prior to the ship's departure from the yard. In the subse-

quent 20 months of service, the set has started 806 times, and operated a total of 151 hours.

Two extremely minor defects have been experienced—a faulty solenoid and a loose battery connection. Total time out of commission has been three hours due to the above difficulties, plus a few hours for scheduled routine maintenance.
This is reliability of the highest order.

The largest shipboard installation in an operational U.S. Naval vessel comprises two 4000 HP Metropolitan-Vickers G-2 turbines in the torpedo boat PT-812. These are high speed boost power units, which operate in conjunction with a highly economical cruising diesel engine plant of 600 SHP. Relatively few operating hours have been accumulated on these engines—170 hours in all. Difficulties have been experienced with warpage of the power turbine exhaust casings, and these will have to be replaced at the next overhaul. Air starter motors are of the piston type, and these have suffered badly cracked casings on both units. Various irritating minor difficulties have also been encountered, and the operational availability of these engines has been somewhat less than desired. Nevertheless, valuable design lessons have been learned from the Navy's first combination diesel and gas turbine plant. (Nick-named CODAG). The military advantages of this type of plant are so great that it is safe to predict that more will be seen in the future.

Another highly interesting, albeit rather short, Navy experience with gas turbine ship propulsion was obtained by mounting four 5000 HP Pratt & Whitney T-34 turboprop engines above the main deck of a Liberty Ship. For this particular test, it was necessary to avoid the use of normal water propellers. A nearby underwater explosion during the test deluged the turbines (operating at full power) with tons of salt water and mud. Despite this rough treatment, three of the four engines continued to operate until shut down. These same three engines were started successfully again the next morning. The mud and sea shells were washed out of the fourth engine by flushing it out thoroughly with a fire hose, after which it was successfully started and run through the remainder of the test series.

At the other end of the power scale is the versatile and dependable 45 HP Solar T-45 engine, which has been used to drive portable fire pumps, air supply units on minesweepers, de-icer units on ice-breakers, small electric generators, and for fog generators. Some 78 of these units (Figure 3) are now afloat; and operating experience has been accumulated for about five years.

This gas turbine with its single stage centrifugal

TABLE I
Summary of Marine Gas Turbine Engines Now used on U. S. Naval Vessels

Engine Designation	Rating HP	Application	Vessel Type	Number	Number Engines Installed	Total HP Installed	Total* Hrs. Operation
Solar T-520	500	Emergency generator drive	Destroyer	1	1	500	287
Solar T-520	500	Auxiliary generator drive	Minesweeper	2	4	2,000	3,709
Solar T-522	500	Propulsion	Landing Craft	1	1	500	350
Solar T-522	500	Propulsion	Personnel Boat	1	1	500	800
Metro-Vick G-2	4000	Propulsion	PT Boat	1	2	8,000	170
Boeing 502-6	160	Auxiliary generator drive	Minesweeper	46	184	29,440	73,338
Boeing 502-8C	160	Auxiliary generator drive	Minesweeper	2	2	320	261
Boeing 502-8C	160	Propulsion	Minesweeper	4	4	640	1,629
Boeing 502-10C	220	Propulsion	Landing craft	3	3	660	140
Boeing 502-10C	220	Propulsion	Minesweeper	26	26	5,720	1,469
Boeing 502-10C	220	Auxiliary generator drive	Minesweeper	28	28	6,160	322
Solar T-45	46	Pump drive	PT Boat	1	1	46	10
Solar T-45	46	Deicer	Ice breaker	1	1	46	**10
Solar T-45	——	Air Supply	Minesweeper	62	76	—	†1,995
Boeing 500-10C	——	Fog generator	Landing craft	7	7	—	†—
				186	341	54,532	84,490

* All hours as of 1 November 1958.
** Being evaluated.
† All installations not complete.

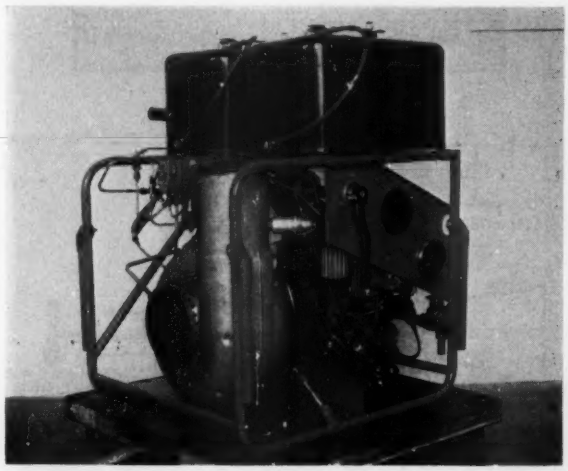


Figure 3—Portable Fire Pump, powered by Solar 45 HP gas turbine.

compressor, radial inflow turbine and hand starting arrangement, is quite simple and rugged. It has proved exceptionally dependable in service, especially in starting in all kinds of weather and under the most adverse maintenance conditions.

A thorough program of simulated service testing was prosecuted both at the manufacturer's plant and at the U.S. Naval Engineering Experiment Station before the T-45 turbine was installed aboard ship. As a result, in-service casualties have been few. The only serious problem has been a series of failures due to corrosion of internal parts of the acceleration control. Malfunctioning of this component allowed unscheduled fuel to enter the combustion chamber, resulting in compressor surge and turbine overtemperature. Corrosion was found to be due to condensation and occasional traces of salt water in the diesel fuel. The difficulty was remedied by use of non-corrosive metals for the defective parts.

A secondary general problem has been noise suppression of these units. Almost all applications are severely weight-limited; and the degree of silencing that can be worked out within the allowable weight has been somewhat less than optimum.

Table I tabulates the marine gas turbines presently in use in U.S. Naval vessels. The operating experience here represented has unquestionably established the gas turbine in a position of respect and rapidly expanding importance in the modern Navy. Operational reliability has proved to be excellent and maintenance requirements exceptionally low, for those engines which have been well designed and thoroughly tested under simulated service conditions before installation. No longer an experimental marine prime mover, the gas turbine is playing an ever-increasing role in improving the military characteristics of our fighting ships.

II—Operating Experience with the GTV *John Sergeant*

By ROBERT L. JACKSON

The GTV *John Sergeant*, Figure 4, has completed two years of very successful commercial operation in the North Atlantic which has included one trip through the ice to northern Greenland and one trip through the Mediterranean. A total of ten round trip long sea passages has been completed in addition to many coastwise passages in the United States and Europe. Since the gas turbine was installed, the ship has covered 94,701 miles. There has been but one short sea delay caused by the gas turbine equipment and that was a failure in the starting clutch. The gas turbine itself has operated with no difficulty whatsoever and engine maintenance expense so far has been zero.

The *Sergeant* is an experimental ship which was conceived, along with three others, to test, among other things, the comparative performance of gas turbine, steam turbine, geared diesel, and free-piston engines under comparable operating conditions. All of the four vessels have seen sea serivce and except for the steam ship which has been recently retired and laid up, are currently operating. A direct comparison of the operating records of the four ships would be of interest.

Experiments of this magnitude can be enormously expensive so in order to keep costs down maximum use was made of existing hulls and equipment. The gas turbine itself, used in the *Sergeant*, is an adaptation of an existing General Electric design. In order to make use of maximum existing equipment and make a minimum of structural and arrangement changes, some compromises in the arrangement and location of various components were necessary. These compromises have not, however, had a serious effect on operations. In a new design of ship and engine, the arrangement and location of ducting, regenerators, fuel treating and so forth could be greatly improved. Before discussing some of the operating experience let us review briefly the description of the engine. The contract specified power output of 6000 HP

Figure 4—Aerial View of GTS *John Sergeant* at Sea.

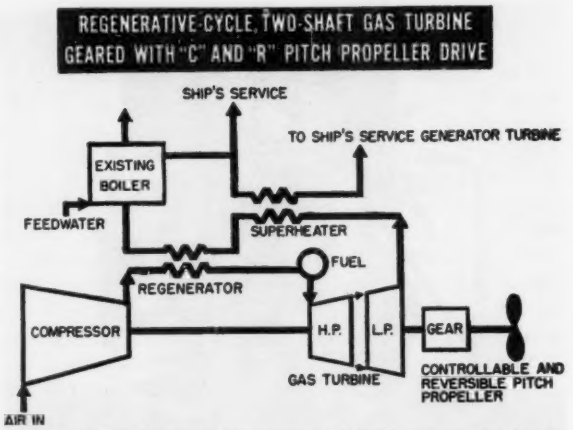


Figure 5—Schematic Diagram of G.E. Regenerative-Cycle, Two-Shaft Gas Turbine Geared to a Controllable and Reversible Pitch Propeller.

normal and 6600 HP maximum at an ambient temperature of 80°F. A waste heat boiler (actually the original ship boiler) was to be installed in the regenerator outlet duct. The specified design overall ships fuel rate was 0.526 lbs. per shaft horsepower hour at 6000 HP. Design specifications were easily met during trials in September 1956 when an output of 7500 HP was actually attained. The trial fuel consumption was 0.519 lbs. per SHP hour.

The gas turbine was adapted from a two-shaft, regenerative-cycle machine which was originally designed for industrial service (Figure 5). The design air flow is 98 lbs. per second, compressor pressure ratio is 4.9 to 1, maximum turbine inlet temperature is 1450°F, and maximum turbine exhause temperature is 950°F. The cross section, Figure 6, shows the general construction of the machine. The turbine is mounted on an integral base which contains all of the gas turbine auxiliaries and accessories, such as lube tank and pumps, controls, starting turbine and so forth.

Figure 7 shows the arrangement of the machinery in the ship. The regenerators and ducting are mounted above the unit and the waste heat boilers over the regenerators. The air inlet is the louvered opening just forward of the stack and directly abaft the bridge. The overhead arrangement of ducts and regenerators makes it very difficult to lift the top casings of the gas turbine. After the second voyage the casing top halves were lifted a few inches, which

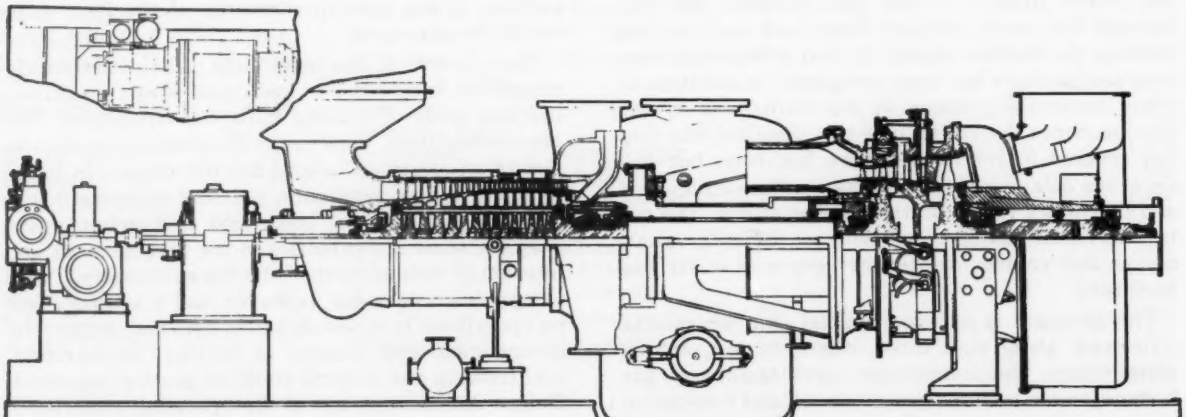


Figure 6—Cross Section of G.E. Regenerative-Cycle, Two-Shaft Gas Turbine for GTS *John Sergeant*.

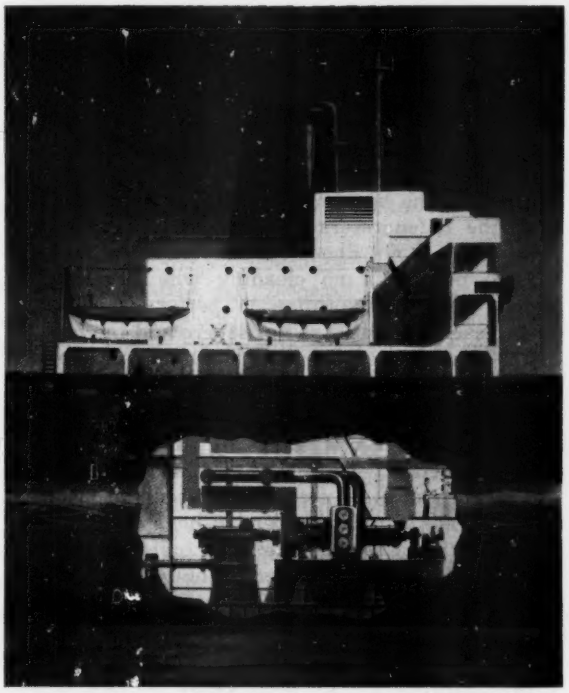


Figure 7—Artist's Conception of Engine Room, GTS John Sergeant.

could be done without disturbing the ducts, permitting visual inspection of some of the blading. This is the only time that the machine has been opened since it was put in service. Turbine nozzles and buckets can be partially inspected through the combustion chambers and from the exhaust hood. No deterioration has been apparent to date.

In regard to engine operating time, a total of about 7000 hours have been logged. Of these 7000 hours, 4700 have been on residual fuel. The first 2½ trips were completed on distillate fuel. This was done in order to permit the crew to become thoroughly familiar with the machinery and to shake down the entire propulsion plant before beginning to burn residual fuel. The first 2½ trips thus accounted for some 1700 hours on distillate fuel. When residual fuel was first burned, the practice of switching to residual fuel after the pilot was dropped after leaving port and back to distillate fuel when the pilot was picked up for entering port was adopted, and thus distillate fuel was burned for maneuvering when entering or leaving port. This practice accounted for another 200 hours or so of distillate fuel operation. More recently, however, the ship has operated on residual fuel virtually from dock to dock as the crew has become more familiar with the machinery and has gained confidence in its operation. The remaining 400 hours of logged time is factory test-stand time.

So far, the fuel used by the *Sergeant* has been a Carapito fuel supplied by Esso and available in New York. This happens to be the same fuel used by the SS *United States*. It contains 58 ppm of vanadium and 15 ppm of sodium in the oil. This fuel is washed and treated on board ship to reduce the sodium to less than 2.5 ppm and to inhibit vanadium by adding about 180 ppm of magnesium. The magnesium is added as a water solution of magnesium sulphate or Epsom salts. The amount of Epsom salts used during the 4700 hours of residual fuel operation has totaled 34,800 lbs. at a cost of 4½ cent per pound. Using a ship's fuel rate of 0.52 lbs. per HP hour, an average power of 6000 HP, and a fuel cost of $2.90 per barrel, the residual fuel treatment has added 1.26 per cent to the fuel price or less than 4 cents per barrel. The use of higher vanadium fuels would require proportionately more magnesium.

The over-all operation of the fuel treating system has been good with a total of 42,857 barrels of fuel having been washed and treated. The fuel is normally washed continuously and the washed fuel is stored in day tanks which have a two day capacity at 6000 HP. Treatment is added as the fuel is withdrawn from the day tank to the gas turbine fuel pump. The schematic diagram, Figure 8, shows the washing system. Two deficiencies which are now obvious and which have been recently corrected existed in the washing system. These deficiencies were in the settling tank and recycle system. As can be seen, the sludge from the centrifuges is sent to a settling tank to separate the oil and combustibles in the sludge from the water and solids so that the combustibles can be returned to the fuel oil through the recycle pump and system so as not to incur loss of combustible because of the centrifuge operation. The tank was originally designed to operate only partially full, that is, with free surface, and the filters in the recycle line had very small capacity. Operation was fine in good weather but in rough weather, the settling tank became a mixing tank and the sludge quickly filled and clogged the small capacity strainers which would then require very frequent manual cleaning—a dirty and bothersome chore. Recently, the tank has been modified to eliminate the free

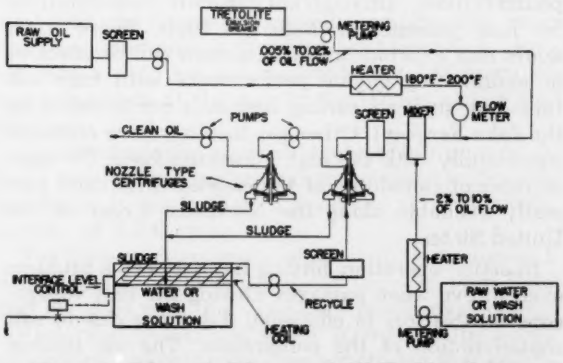


Figure 8—Schematic Diagram of Oil Washing System

surface and thus greatly reduce the stirring action in rough weather, and the recycle filters have been changed to a larger capacity type which can be blown down to the sludge tank rather than cleaned manually. As a result of these changes, greatly improved operation is anticipated. Except for the deficiencies noted the washing system virtually runs itself and with the corrections described, the system should now operate with very little attention even in rough weather.

Critics of the gas turbine have frequently pointed to the "necessity" for the *Sergeant* to burn a "special" fuel. Actually, that is not the case. The only real requirement is that the fuel, when treated, meet the specification of having low sodium content and a ratio of magnesium to vanadium of at least 3 to 1. So far, no fuel has been found which cannot be washed and treated to specification, but all fuels of course have not yet been encountered. A number of different fuels have been washed and treated in systems similar to the *Sergeant's*. The *Sergeant* has washed several fuels successfully and among these were fuels from the Middle East picked up at Bordeaux and Bremerhaven. One fuel, taken on board at Southampton, proved difficult to wash until the correct emulsion breaker was used, after which washing was very satisfactory.

The ship will, in all liklihood, be restricted to the use of comparatively low vanadium fuels for average long time operation until two existing conditions are changed. First, an easier method of getting the magnesium sulphate to the mixing tank is required. At present, the treating system is so arranged that the 100 pound bags of magnesium sulphate must be carried by hand from the storage compartment to the mixing tanks two decks below via steep steel ladders —a real chore in rough weather and barely manageable when only one or two bags are required per day. Some mechanical help, such as a hoist, or better yet, a mixing tank, at the storage location with the solution piped to the point of use would be of tremendous help. In other words, the materials handling needs vast improvement. Second, a turbine cleaning system embodying the injection of cleaning compound is likely, although not certainly, to be required for long passages on high ash fuels. There is no doubt that a turbine cleaning system will be effective in maintaining engine performance with high ash fuels but, such a cleaning system is not installed on the *John Sergeant*. Other gas turbines have operated successfully with the high vanadium fuels, 300 ppm or more of vanadium, of Venezuelan origin and normally available along the Northeast Coast of the United States.

In actual operation, fouling has not been a problem even in two week passages. During the first voyage, considerable loss in efficiency did occur due to salt contamination of the compressor. The air intakes faced the side of the ship and during dirty weather, a usual wintertime North Atlantic condition, salt spray entered like rain and literally ran on the louvers. Since then, hoods have been fitted over the louvered openings so that air enters only from aft, and compressor contamination has been reduced to a negligible level. It was orginally felt that regenerator fouling might occur so lance openings were provided to blow off the accumulated ash. In practice, however, the regenerators have not required cleaning and lancing is not done. The turbines operate from port to port with no cleaning whatsoever. Even though some deterioration in performance occurs during each passage it is not severe and the plant is completely restored by water washing turbines and compressors at the end of each long voyage.

An idea of the magnitude of deterioration in performance which takes place, can be gained by comparing the actual performance against the guaranteed trial performance. As previously stated, the specification fuel rate is 0.526 lbs. per HP hour over-all ship. In trans Atlantic service, the usual fuel rate has been between 0.52 and 0.53 lbs. per HP hour. This includes the effect of fouling, part load operation in maneuvering, and so forth. Horsepower cannot be precisely determined but it is estimated from trial and calculated data, factoring in ship's speed, propeller pitch, and RPM. Mr. William Van Cott, the Chief Engineer of the *John Sergeant* feels that his estimate of horsepower is, if anything, low so that the SFC he determines from horsepower and fuel consumption by tank soundings is conservative. There have been voyages with SFC as low as 0.49. The reason for the exceptional fuel performance in service compared to the specified and guaranteed fuel rates has been the result of two important factors: first, the ambient temperature in the North Atlantic averages almost 30°F below the guaranteed rating ambient of 80°F and second, the Chief Engineer has been meticulous to operate the turbine at maximum allowable temperature. The actual fuel consumption of the *Sergeant* in service can be very favorably compared to the in-service fuel rates of existing and projected steam ships.

A point that should be made here is that the gas turbine is an inherently simple and packaged power plant which is easy to operate at its optimum performance. Only one variable need be controlled and that is temperature. The temperature may be controlled either manually or automatically, in order to achieve the optimum in performance.

Unfortunately, the heralded engine control from the bridge of the *John Sergeant* has not materialized in practice. This, however, is failure of detail rather than principle. The exhaust temperature control which was selected for the turbine has the unfortunate characteristic of a long delay and considerable overshoot in temperature indication because one element of the bi-metallic sensor equipment becomes fouled with ash. The overshoot has led to danger of

machine trip-out because of overtemperature when operated on the single lever bridge control. A new exhaust temperature sensing element which will eliminate the conflicting expansion characteristics caused by fouling of the bi-metal sensor and thus remove the danger of overshoot and machine trip-out will make the bridge control a practical reality with all of the attendant advantages of ship maneuvering in tight quarters.

With respect to maneuvering ability, even without the bridge control, the *Sergeant* has, indeed, done very well. The controllable and reversible pitch propeller has had a definite and favorable effect on the ship's maneuverability. Not only can the ship stop in a fraction of the usual ahead reach because of her ability to apply full power, and more than full torque, to astern operation, but she responds well to frequent and rapid maneuvering signals. On her recent trip to the north of Greenland she was the only single screw vessel in the convoy behind an ice breaker for four hundred miles through the ice. The other vessels, with twin screws, were able to easily negotiate the sharp turns dictated by the breaker's choice of easiest path through the ice—the single screw *Sergeant,* however, had to back and go ahead several times to make each turn. The result was a record of 1700 signals to the engine in a four-day period at a rate of one engine signal to change speed or back down every two minutes during most of the trip. In future installations, such constant and varied demands on the engine can be made even easier. Under these close maneuvering conditions and during docking, direct control of the engine from the bridge will be a distinct advantage over usual practice.

The results of two years operation of the *John Sergeant* have been very favorable. The results have disclosed the gas turbine as having a distinct place in large vessel propulsion since it offers advantages in manning scales, in fuel rate and in maneuverability. Further advantages in fuel rate can be had with an intercooled gas turbine cycle. This cycle can offer about a 10 per cent improvement in fuel rate over that of the *John Sergeant* with concommitant advantages of less space and weight with no sacrifice in ease of operation and maneuverability.

The operating experience of the *John Sergeant* has proven the usefulness of the gas turbine as a power plant at sea. She has operated well on residual fuels, has answered the exacting requirements of commercial operation and has gained the enthusiasm of the crew who operate her as a practical advancement in marine propulsion. In the future more gas turbines will be used at sea because they make economic sense.

III—Some Marine Propulsion and Generator Set Applications of a 500 HP Gas Turbine

By P. A. PITT, and P. G. CARLSON

This year marks the tenth anniversary of our association with the Bureau of Ships and Marine Gas Turbines. In these ten years the acceptance of the marine gas turbine hasn't been as revolutionary as it has been in aircraft. In aircraft the advantages of the gas turbine are so pronounced that the users were willing to put up with initial unreliability and short life in order to apply the gas turbine. However, in the case of the marine gas turbine with the Navy, the progress has been steady through the years and it has been very gratifying to see throughout the Bureau of Ships people that were formerly opposed to gas turbines finally becoming enthusiastic supporters or, in certain cases, at least accepting their use where no other power plant would accomplish the mission.

It has also been gratifying to see the engineering officers and the crews of vessels equipped with gas turbines view the new power plants with skepticism and, within a year or two, become enthusiastic supporters, going out of their way to voice their opinions and recommend them for other applications.

This paper will outline the current status of a number of installations of our 500 horsepower gas turbine engine. The engine has been described and, in some cases, operating experience has also been detailed in previous ASME papers. My purpose herein is to more or less bring up-to-date our marine experience.

PROPULSION APPLICATIONS

This installation and the early operating experience of the 40-foot personnel boat, the *Solar Meteor* was discussed in a paper presented at the 1956 Annual Meeting. The engine was installed in February 1956 and was recently removed for inspection, so it has completed almost three years of operation, during which time we accumulated over 700 hours of operation both at the bay at San Diego and in the open sea.

This boat weighs approximately 18,000 pounds. It has a wooden hull and its maximum speed is 29 miles per hour. It has a 27-inch propeller, 17-inch pitch, turning at 2,000 r.p.m.

For these various boats which will be discussed, I would like to point out that the types of propellers that are used with this same horsepower engine vary considerably in size and speed. Knowing little about propellers, I have come to the conclusion that select-

ing a propeller for small high-speed craft is a rather unscientific and empirical business.

During the two and a half year program we removed the gas turbine engine twice; once to correct an oil leak and at another time to check a turbine seal rub that was heard. The latter turned out to be of little consequence and we put the engine back together again without modification.

In October of this year we began to wonder how the engine looked inside, and further we wanted to apply some of the information that we could learn to newer designs. For these reasons the engine was removed. We opened it up, looked at it, and the only thing of any significance discovered was the rather heavy axial rub between the second stage turbine nozzle and the second stage turbine wheel. The turbine nozzle diaphragm had deflected axially and had fouled the wheel and rubbed a sixteenth of an inch groove in the rim of the wheel. We now have a different type of nozzle diaphragm in which the inner ring, outer ring, and vanes are all cast in one piece. This is a very rugged nozzle, and while I would like to say that we foresaw the trouble and made this

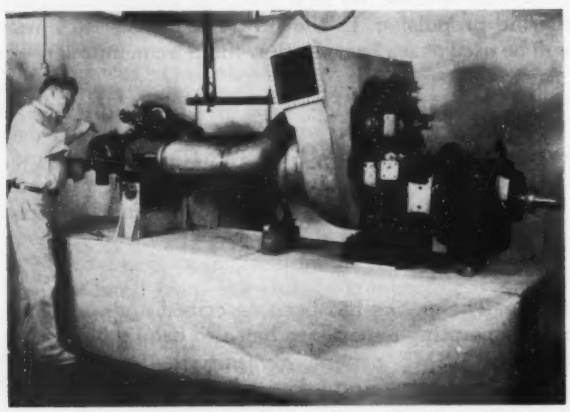


Figure 9—T-522 Engine on *Meteor*

change, the principal reason for the change was cost reduction.

This engine employs moderate silencing and while idling it was a little bit noisier than the equivalent diesel normally installed in the 40-foot personnel boat. However, at full load the gas turbine ran quieter than the diesel. We actually checked this with sound level meters.

One of the interesting things that we learned about this boat was that we thought there might be some problem with the power turbine over-speeding when declutched for reversing. This did not happen since apparently the gear had declutched in such a short time that the power turbine didn't have a chance to reach tripping speed. However, the engine did trip out when backing down, due to cavitation of the propeller. Cavitation caused the load to drop off and

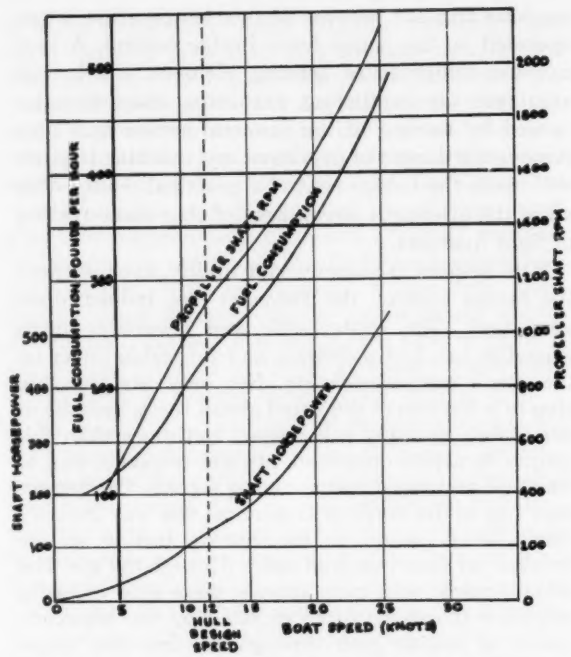


Figure 10—Performance Characteristics of *Meteor*

Figure 11—40 Foot Steel-Hulled LCPL

the engine would trip out due to over-speeding. We installed a special topping governor on the power turbine which set the fuel flow back to idle instead of tripping out the engine, and that seems to have solved the problem.

Figure 9 is a picture of this engine. The air is taken into the compressor near the middle of the engine, flows forward, then is collected, flows back through the single-can combustor and through the three-stage turbine. The third turbine stage is mechanically disconnected from the remaining portion of the rotor, and thereby provides shaft power output. A reduction gear reduces the speed from 20,000 to 2,000 r.p.m.

A hydraulically actuated reverse gear is mounted on the output side of the reduction gear.

At the forward end we have the accessory drive gearbox mounting the starter. The big casing shown is the exhaust collector which takes the exhaust out to each side of the boat with an eductor action that serves to cool the engine compartment. We spray water into the exhaust to prevent overheating docks or other boats.

In Figure 10 are given the performance characteristics of this 40-foot personnel boat. You might be interested in the specific fuel consumption; approximately 0.9 pounds per horsepower-hour. At full load the boat uses between 50 and 60 gallons per hour.

The next figure, Figure 11, shows the 40-foot steel-hulled LCPL. This has undergone extensive evaluation tests and is now in use by the underwater demolition teams. This boat weighs about 19,000 pounds. The power plant, including a sub-base and all the accessories, weighs about 2,100 pounds. This boat went into service in March of 1957 and, to date, has accumulated over 380 hours of operation and 2,000 starts. This boat has a 27-inch propeller with a 24-inch pitch, turning at 1,600 r.p.m.

The underwater demolition teams are quite happy with this gas turbine boat as compared to the diesel boat, first, because it has quite a low silhouette. This hull was designed for gas turbine use and they took advantage of the reduced height of the gas turbine; the resulting low silhouette makes radar detection difficult. Second, it has a considerably lower noise level than the diesel boats. Finally, and most important, the speed is increased to over 25 knots.

The Navy did some extensive silencing on this unit by lining the air inlet ducts with foam plastic and it is now a very quiet boat. They use lined louvers or splitters in the air inlet, and the underwater demolition teams are now able to take this boat where others would be detected.

Also, they like the very good acceleration. One of the most commented upon features of the gas turbine boat is rapid acceleration resulting from the torque charateristic of the split wheel gas turbine. The boat can stop in a very short distance; actually in less than 150 feet from a full speed of 25 knots to dead in the water. Also, because of this high torque characteristic, it is good at backing off the beach.

The problems that we have had here have been rather miner in nature. Some corroding of the electrical connectors has occurred. We had been using aircraft-type connectors and we are currently looking at some other types to better withstand salt water corrosion. One other problem has been the fouling of the compressor due to salt water. The air intakes for the engine are located near the operating panel in the cockpit and, in rough water, take quite a bit of salt water aboard which makes it necessary to clean frequently. In some cases where the water is rough, we have had to clean the engine every 50 hours or so.

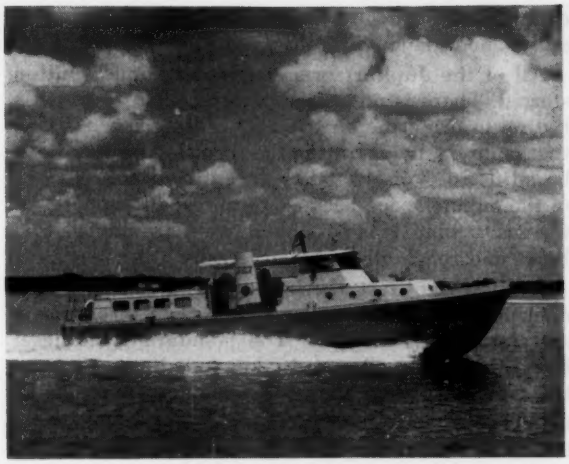


Figure 12—Sewart Offshore Crew Boat

Other times, it will be as long as 200 hours before cleaning is required.

Our method of cleaning is quite different from the water washing described in the previous paper. We use what is known as carbo-blasting. With the engine running at idling speed we inject ligno-cellulose pellets (ground-up walnut sheels or peach pits) into the engine. This is an abrasive and removes the deposits from the blading. Our tests on water washing weren't too successful. We were not able to restore full power with this technique. That is possibly because the water in San Diego is so hard that it began to build up deposits. This we actually demonstrated. After injecting salt water into an engine and checking the power level, we began to inject fresh water. By monitoring power output, we notice a rise and than a drop-off in power apparently due to deposition from the fresh water. It takes about half an hour on this boat to carbo-blast and it is fairly easy to do. It can actually be done faster by making better provision in the air inlet ducting for the introduction of the carbo-blast material.

Figure 12 is a photograph of the new offshore crew boat which has two 500 horsepower engines. This boat was built by Sewart Seacraft. It is 55 feet long, weighs approximately 50,000 pounds and was first run in June of this year. The maximum speed is approximately 35 miles per hour. It has accumulated 160 hours of operation to date, with about 438 starts. This is a steel-hulled vessel. The propeller in this case is 29-inches in diameter, has a 39-inch pitch and turns at only 1,200 r.p.m.

The impression by observers in this case is the low vibration as compared to diesel boats, particularly in turns. They tell us that when a turn is made with twin-screw diesel boats, the inside engine slows down more than the outside engine, making for boat vibration. In the gas turbine boat both engines slow down and remain at the same speed and there is considerably less vibration felt. Again, boat acceleration was

commented on by the users. They also commented on its good maneuverability and ease of starting.

All of the Jupiter series engines are push-button started. There is no other operation than to touch a button to bring the engine up to idling speed. From that point on, by operating the throttle, the speed can be adjusted. This boat has exceptional accessibility in the engine space because of the small diameter of the gas turbine. It is possible to walk around the turbines and reach all parts very easily.

In one recent test, the boat covered 43 miles from dockside to an offshore rig in the Gulf in one hour and forty-eight minutes. The standard twin-diesel boat that is normally used takes four hours to make the same trip. Since the boat accommodates some 28 people, always on overtime pay when being transported to or from a rig, you can readily see that the savings in labor costs are appreciable.

The crew learned very rapidly to operate the engines and are quite enthusiastic about its performance. One problem encountered, however: the air inlet ducts were located near the operator's panel and no precautions were taken as far as silencing was concerned. This produced a rather high noise level on deck. However, the application of one-inch fiberglass to line the inlet air ducts resulted in a lower sound level than a comparable diesel boat.

A view of the engine compartment in this boat is shown in Figure 13. The reduction gear, part of the reverse gear, and a portion of the combustion chamber can all be seen.

In Figure 14 are shown sketches of the Sewart boat mentioned above as well as another boat that was recently operated for the first time. This latter boat is made by Higgins. It is 52 feet long, has an aluminum hull, weighs approximately 43,300 pounds, and employs a V-drive. To date, this boat has achieved a speed of 39.5 miles an hour.

Boat builders have found that formulae for propeller selection for diesel boats do not seem to apply to gas turbines. No good theory has been advanced for this discrepancy but, as a further example, the propellers in this boat are 26-inches in diameter, 32-inch pitch, and turn at 1600 r.p.m. Different types of propellers are currently being tried on the Higgins boat.

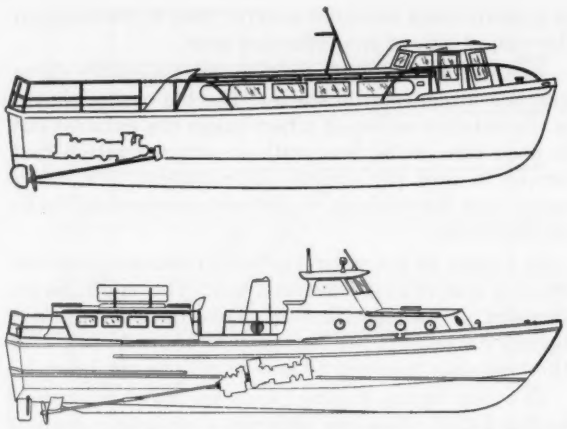


Figure 14—Sketches of Sewart Boat (Bottom) and Higgins Boat (Top).

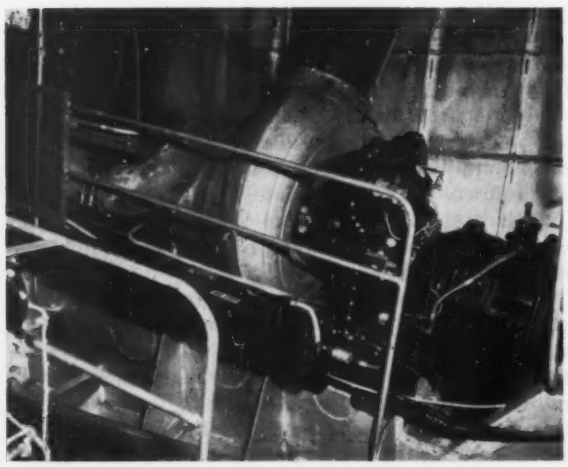


Figure 13—Engine Compartment of Sewart Boat

GENERATOR SET APPLICATIONS

With regard to the generator set applications of Jupiter gas turbines, it should be noted that here we employ a single-shaft version of the engine. This is done by bolting the third turbine stage rigidly to the other two so that the entire compressor and turbine assembly rotates on a common shaft. One of the most successful applications of gas turbine generator drives has been on minesweepers. A typical minesweeping boat utilizing gas turbines is shown in Figure 15. The MSB-28 and -29 boats were equipped with twin 200 kw d-c pulse generators driven by the Solar gas turbine. The MSB-28, a 57-foot wooden hull, non-magnetic vessel went into service in March of 1954. An accelerated life test of 1500 hours duration was run after which the engines were sent back to Solar for inspection. Very few significant difficul-

Figure 15—U.S. Navy MSB-29

ties were revealed. Some fretting of the accessory drive splines and some inter-granular corrosion of the compressor stator vanes had occurred. The stator vanes were cast from Type 316 (18-8) stainless steel which apparently became sensitized when the assemblies were brazed. The salt water evidently caused intergranular corrosion. Again, a material change (to a 12-chrome rolled steel stock) appears to have eliminated the problem. The rotor blades have always been fabricated form the 12-chrome steel and have not suffered from salt water corrosion. A detailed description of the engines after the 1500-hour test was reported in an ASME paper presented in the fall of 1957.

The availability of generator sets in the MSB-28 is estimated to be over 95 per cent, and the problems encountered have been entirely confined to the control and fuel systems. On the initial engines we had some trouble in introducing the cooling air into the turbine rotor. This was done by bringing air bled from the compressor around the engine, through a rotating seal, and into the back of the third-stage turbine wheel. The design was modified some years ago to bring the cooling air through the center of the compressor drum, through the turbine shaft and then to the turbine wheel, thus eliminating the rotating air seal which was quite a problem on these boats.

A view of the generator room of the MSB-29 boat is shown in Figure 16. This is a much larger minesweeper; 85 feet instead of the normal 57 feet, and the installation is ideal in many respects; there is considerable space around the engines for servicing, the silencing is good, and the eductor cooling is very effective.

In the MSB-29, only some 80 hours of operation have been accumulated since it was sent into service in March of 1957, but apparently this is the normal usage that one of these minesweepers gets in peacetime. This brings home the point that the accelerated service tests that the Navy conducts are very valuable, since in normal service it is sometimes years before enough hours are accumulated to determine the durability of new equipment.

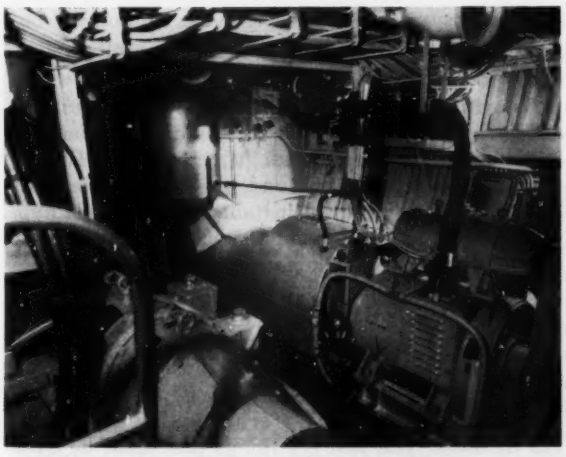


Figure 16—Engine Room, MSB-29

A 250 kw emergency generator set replaced the prototype gas turbine unit in USS *Timmerman* (DD-728). It accumulated some 300 hours of operation on board before the ship was decommissioned in July of 1956. The availability and reliability of this set were very good. The unit consists of a T-520 single-shaft 500 horsepower gas turbine engine and an 8000 r.p.m., 400-cycle generator. It is quite interesting to note that the 250 kw 400-cycle generator weighs only 650 pounds, which compares to approximately 3000 pounds for a similar capacity 60-cycle generator. The total weight of the entire set was only 1500 pounds. It should be noted that no sub-base was used with this unit; the set was simply bolted down to the deck using mounting trunnions from the casing of the generator.

One interesting event which occurred during the operation of this ship: during a rather severe storm, when the *Timmerman* was shipping green water as high as the bridge, a considerable quantity of water was taken into the compressor air inlet duct. Although the engine was not running at the time, several gallons of salt water collected in the duct since there was no provision for draining the duct at that time. While the water was still contained within the ducting, a start was attempted. The engine fired but did not accelerate, and soon "flamed-out" with water dripping from the various flanges of the unit. A week or so later a service engineer found the rotor seized by the build-up of salt crystals. After breaking the rotor free with a wrench and injecting fresh water into the compressor inlet, the engine was restarted and operated for more than 150 hours before decommissioning of the ship. Since removal from the ship, this generator set has been used in a project that has received recent notice in the newspapers. Kaman Aircraft employed the unit as a power source for an electric motor-powered helicopter. In this application the gas turbine generator set on the ground supplies electric power through a cable to the motor mounted on the helicopter. During the course of this testing, some stator vanes failed and again inter-granular corrosion of the vanes, as discussed previously, was found to be the culprit. Corrective action as mentioned above was taken and the unit is now back in operation.

In Figure 17, the 300 kw gas turbine emergency generator set now installed on board the USS *Gyatt* is shown. This unit has compiled a remarkable record, very close to 100 per cent, for reliability and availability since the ship went into service in March of 1957. Before the ship went into service some difficulty was encountered with the fuel-air starter used to provide the rapid starts and with fuel metering during acceleration. The problems were resolved, however, and no further problems of any consequence

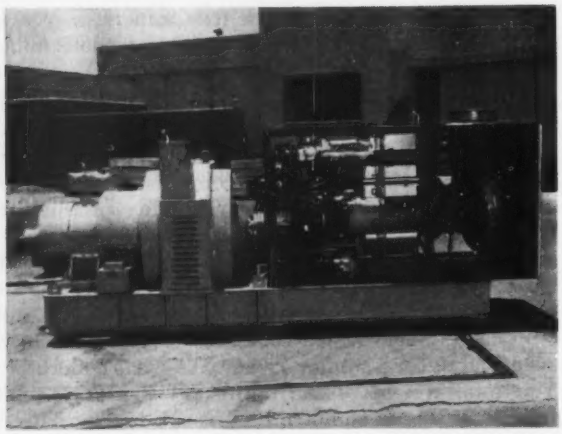


Figure 17—300 KW Gas Turbine Emergency Generator Set on USS *Gyatt*.

have been encountered. The generator set weighs 7350 pounds.

The final generator set to be discussed is shown in Figure 18. This is the 300 kw package generator set which is a variation of the *Gyatt* set. In order to conserve space as far as possible, the gas turbine is placed above the generator. A vertical bevel gear train is employed to transmit power to the generator. A light-weight 1800 r.p.m. generator permits an overall generator set weight of approximately 5500 pounds. This unit will be delivered to the Engineering Experiment Station in the very near future for an extensive endurance test.

In summation, we would like to again point out the variety of successful marine applications which have been found for these engines. We feel that in every case these gas turbines have demonstrated a high degree of reliability and low maintenance. We are encouraged by the progress made in the past ten years and look forward to a much broader scope of marine applications in the future.

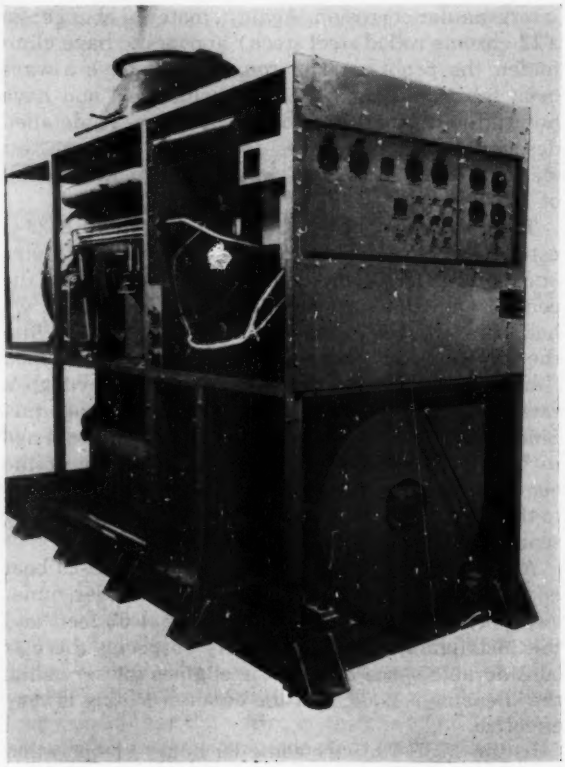


Figure 18—300 KW Package Generator Set (Variation of *Gyatt* Set).

IV—Discussions

MR. WOLMACH, U.S. Navy: What is being done in the way of installing Diesel engines for PT boat propulsion?

COMMANDER MILLS: Well, the use of Diesel fuel in any naval ship or boat has a very great advantage in that you have a safer fuel than gasoline. As far as replacing the particular engines in the PT boat, we have nothing on the docket at present, other than the combined diesel and gas turbine plant described.

MR. WOLMACH: I mean the idea of using diesel engines for main propulsion in a PT.

COMMANDER MILLS: The Diesel's great advantage, of course, is generally a somewhat lower cost than the gas turbine and also somewhat better fuel consumption. That's why we think that this particular type of an installation where you have the Diesel engine for maximum fuel economy under cruising conditions, plus the light weight gas turbine for your boost power, is particularly favorable.

As with many Navy ships and boats, prototypes are built during peace time for rapid reproducibility in times of particular need. At present the PT-812, with Diesels for cruising and gas turbines for peak load is an experimental installation or a prototype which could be the forerunner of a type of installation that can be used when needed in larger numbers.

MR. D. S. MCCAULEY, McCauley Engines, Los Angeles: During the war we were contemplating the installation of gas turbines on major vessels such as battleships and large supply ships. Is there any further consideration along this line?

COMMANDER MILLS: We are thinking a lot about gas turbines. The two big things that must be overcome where gas turbines are concerned for ship in-

stallations, are the initial cost, which is generally greater, and the fuel consumption which is generally higher than the diesel or the steam turbine.

Now, fuel consumption does not have the same connotation that it may have in a commercial installation where you are vitally concerned with operating costs; but for a shipboard installation you come into the question of weight. Even though your prime mover may be lighter, if you have to carry a greater weight of fuel to get a given cruising range you may end up with a total weight of machinery plus fuel greater for a lighter gas turbine than it is for a heavier Diesel.

On these applications where we have gas turbines, frequently it has been a case that the cruising range required is so short that the total weight of the machinery plus fuel is less for a gas turbine. With the new turbines coming up that have even better fuel rates, this crossover point (where it becomes advantageous to use the Diesel in lieu of gas turbines, or vice versa) becomes ever more favorable to the gas turbines.

The crossover point has been such that the large ship applications are rather limited. I can assure you that the gas turbine has been given thorough consideration for any ship installation where its use is practicable. Even though we formerly would occasionally install a gas turbine for trial purposes, now that the gas turbine is an established prime mover it's done on the basis of cost, weight, and so forth, just like it would be for any other prime mover.

MR. JAMES M. WHITE: Has there been any use of compound engines or free piston engines? I remember two years ago there were some discussions of marine applications.

COMMANDER MILLS: The United States Navy has studied the free piston compressor gas turbine combination; but we haven't installed any to date, nor do we have any on the books for the immediate future. Of course, you are familiar with the Maritime Commission installation on the *William Patterson,* which the Navy is following with great interest.

MR. ROBERT IRVIN, Ramco: You stated that the sulphur level in fuel was a problem. What sulphur level are you talking about when you say it's a problem?

COMMANDER MILLS: Anything in the neighborhood of 1 per cent or greater has been a problem on the 160 HP and 220 HP minesweeper gas turbines.

MR. IRVIN: In other words, as long as it meets at least the specifications it's all right then, just 1 per cent.

COMMANDER MILLS: Well, the Navy specification diesel fuel will allow up to 1 per cent, and for the particular combustors mentioned, we have had trouble at the maximum allowable sulfur content. This doesn't hold for all combustors, just these particular ones. The combustor met the original purchase specification. It satisfactorily burned any Navy diesel fuels from domestic sources that have been encountered; but this is a problem that is beyond original design requirement you might say.

MR. IRVIN: Did you notice a breakover of just 1 per cent?

COMMANDER MILLS: Just that when we went to the edge, then we began getting more carbon than we could tolerate.

MR. J. S. PASSMAN, Engineering Experimental Station, U.S. Navy: I believe the biggest problem with the high sulphur fuel has been a little deceiving in the fact that the sulphur was a little high. It was more that the end point of the fuel was a little high and caused more coking. The fact that the sulphur was high was somewhat incidental.

MR. IRVIN: At what point did this end point become critical?

MR. PASSMAN: We haven't tested a series of fuels establishing which one becomes critical. I am afraid I can't give you a figure. I think about 670°F or 680°F was the figure, but I can't be sure. It was rather high.

MR. IRVIN: Didn't that meet your Navy spec?

MR. PASSMAN: Yes, the fuel we had been using previuosly was a somewhat high quality fuel under the same Navy specifications as the fuel that Commander Mills is referring to. It was high in sulphur and it was the highest sulphur allowable, and a few other factors also, such as the high end point.

MR. K. J. LOFTHEIM, Army Transportation Corps: In view of your comments to the effect of the high fuel consumption and other things you said about gas turbines, what's your thinking on the basis of your experience as to future applications of regenerators to the turbines that you may use?

COMMANDER MILLS: We would like anything that will get the fuel consumption down to the same ball park as the Diesel. The rotary regenerator looks very interesting. It seems to be one of the most promising things at present, in my opinion, for getting a turbine that will have a Diesel engine fuel rate. We would like one very much.

J. W. REESE, Coast Guard: Commander, two questions. One, what is the current status on that supercharger for the boilers that the Navy was planning to put on the destroyers, I believe. And second, on the larger ship propulsion using the gas turbine, are there any plans to use a reactor for a gas turbine combination?

COMMANDER MILLS: In answer to your first question, the supercharged boiler, which, of course, uses gas turbines to build up the pressure for the firebox, is under test at the Naval Boiler and Turbine Labratory in Philadelphia. The tests are very promising. As to your second one, about the plans for the use of the gas turbine in connection with a nuclear reactor, there are others here who can give a much better picture on that. But the Navy studies all of these things. At present there are none scheduled for installation aboard a U. S. Navy ship.

MR. MCCLURE: In regard to the question of the nuclear reactor, I don't know of any naval programs, but the AEC and the Maritime Administration are going ahead with a program of gas cooled reactors with a gas turbine. If you want any more of a picture of it, I think we can give it to you, but I think this might be sufficient.

CHAIRMAN GOLDSMITH: I think we should make it clear that the AEC has given a contract to the Electric Boat Division of the General Dynamics Corporation for research on a gas reactor with a gas turbine.

COMMANDER MILLS: I might say in this connection that the Maritime Administration has been most generous in furnishing the Navy with information on their experience with gas turbines; and in many ways their experience at sea complements that of the Navy. The Maritime Commission, for example, has the *John Sergeant* installation and they are also doing this gas cooled reactor work. So, the two programs complement each other and there is a very good interchange of information.

MR. J. P. MARZULLO, Gray & Hunt: What is the specific difference between the two fuel rates? You mentioned that the efficiency of the Diesel was greater than the gas turbine. Is there an average difference between the two or does it vary with the horsepower sizes?

COMMANDER MILLS: There is quite a spread. In general I think it is safe to say the Diesel fuel rate varies from 0.35 and 0.5 lbs. per shaft horsepower. On the gas turbines you can pick your own low point; generally for those turbines that we have had operating, the best we have done is 0.7 or 0.8; and they will go up to 1.1. or, in the case of the little fire pump where you are not particularly concerned with fuel economy, it will run up to 2 lbs. per horsepower hour. Some of the new turbines under development will come down to 0.65 or perhaps a little better under the Navy rating.

There may be some confusion from time to time arising from the fact that the Navy doesn't always quote the same horsepower for a given turbine that other people do. That is because, for shipboard installation, we have selected as standard conditions 80°F ambient air, as contrasted to the aircraft rating of 59°F. We also rate the engines at 4 inches of water depression on the intake and 6 inches of water back pressure on the exhaust. This penalizes the engines somewhat when it comes to stating the horsepower and fuel consumption ratings.

CHAIRMAN GOLDSMITH: I think in all fairness cognizance should be taken on a marine diesel engine of your double pumping of water. The power that it takes to pump the salt water to cool the fresh water has to be added to your specific fuel consumption on your Diesel engine which, in some cases, is a rather good percentage.

I have seen a lot of figures quoted that are based on brake horsepower tests of the engine which is not entirely fair in a marine job as compared with the gas turbine, where you don't have to pump water.

CHAIRMAN GOLDSMITH: A question I would like to ask is, and I think it is pertinent because it is something I observed on the trial trip, and I would like to know this for a matter of record: What is the ratio of horsepower ability with temperature? In other words, in the North Atlantic, between the temperatures of winter there and the temperatures you get, say, in the summer. What horsepower maximum and minimum can you get with change in temperature? It is quite large, I believe.

MR. JACKSON: Yes, the gas turbine is responsive to ambient temperature. A decrease of 40° in the ambient temperature will result in an increase in power capability of about 25 per cent. Now, this number depends on the particular design and so forth, so it's not a whole number but it is approximately that. The *Sergeant* however, has been operating mostly at 6,000 horsepower. She slows down when the weather gets too bad and there are occasions when she has run higher power, but the usual has been 6,000 independent of ambience.

MR. D. C. ARCHER, Esso Standard Oil: Do you have intake filters in the louver section or are you operating without filters?

MR. JACKSON: No, there are no filters installed. The atmosphere at sea is generally pretty clean. That is the only reason.

MR. IRVIN: One thing you mentioned which I want to clarify. They didn't move those boilers on that ship, did they? You mentioned they were above the gas turbines, actually they are forward, aren't they?

MR. JACKSON: No, they are above the gas turbine.

MR. IRVIN: Then they have actually relocated the boilers.

MR. JACKSON: Yes, I believe so. Will you confirm that, Mr. Tangerini?

MR. C. TANGERINI, Maritime Administration: That's right. Out of two original boilers, only one was salvaged and that was converted to a waste heat boiler and set up on the second deck, well above the engine and aft.

MR. IBVIN: You mentioned this ship was in service for two years. What was the drop-off in efficiency from, say, the initial six-month period and the latter six-month period?

MR. JACKSON: As far as we know it is the same as when it went into service. The compressor and turbine are washed at the end of each trip and efficiency is completely restored.

MR. IRVIN: What do you wash it with?

MR. JACKSON: Plain water, fresh water, that is, not sea water.

MR. LOCKMAN: You say you wash the machinery, would you tell us a little more in detail what you do?

MR. JACKSON: Well, rather than say that I did it, it is what the Chief Engineer on the ship does. He developed this system. It is quite simple: he runs

the high pressure set consisting of the compressor and the compressor turbine at starting speed, which is about 10 per cent of actual speed. He runs the load set on the turbine which also rotates the propeller and the reduction gear. He then water washes the compressor by just running water into the air intake and it goes out the drain. He removes the fuel nozzles from the combustion chambers and sticks a rubber hose about six feet long down through the nozzle opening up near the first stage nozzle, and he washes through each chamber in turn until the water runs clean. He doesn't have any special equipment installed for washing.

MR. MARZULLO: You mentioned that he kept his temperature up in order to keep his horsepower or his specific fuel consumption down. What is the 1450°F that you mentioned, was that the maximum operating or could the machine be operated higher?

MR. JACKSON: 1450°F was the maximum specified firing temperature and that's the temperature at which it has been substantially operated.

MR. E. HORN, Diamond Chemical: Will you repeat your parts per million of vanadium and sulphur?

MR. JACKSON: The fuel which the *Sergeant* actually uses?

MR. HORN: Yes.

MR. JACKSON: That was 58 parts per million vanadium, 15 parts per million sodium. That is the fuel the *Sergeant* is actually using.

MR. MCCAULEY: I still have a point in my mind I would like to get cleared up. What would be the relative advantages or disadvantages of using 4 to 6 high speed turbines mounted on the hull driving through a generator to a motor-driven shaft?

MR. JACKSON: Well, I don't think I had better try to answer that one.

CHAIRMAN GOLDSMITH: I would sure like to answer that one. I have very little ability to work out a formula that has two "x's" in it and I feel very strongly that by adding a reversible propeller of a size untried, which is adding an extra "x" to this formula, and I don't see myself why they shouldn't be electric drive.

MR. TANGERINI: I would like to emphasize or underscore something that Mr. Jackson brought up before. I had occasion to check on the logs of the *Sergeant* right up until this recent round trip, and the fuel rate for all trans-Atlantic passages, 22 inbound and outbound. Here are the averages of about an 8 to 10-day run, each way, and 11 trips—that would be 22 runs—these are long runs, they are not small passages—all of them averaged 6,000 horsepower in round numbers.

There is one thing I want to point out, that the low fuel rate of this ship is not only due to the engine, it has also been accomplished by reason of regenerators. But we go even further because the waste heat boiler on this ship is giving us a tremendous recovery, on this old Liberty ship where we have a tremendous need for steam, a capacity of about 7,000 lbs. of steam per hour. We have a variety of equipment that is original, evaporators, about 16 pumps, including fire and general service and bilge. We have an awful lot of heating for quarters where we had to build the midship house to get more space for personnel. And we have a lot more heating need for this fuel washing system that Mr. Jackson talked about. Now if we had a fresh start the chances are we would eliminate all the steam equipment and put in a house boiler and some automatic starting, package type boiler. Also we would probably install a little heavier or larger regenerator, probably with an 85 per cent effectiveness instead of the 79 per cent that we have.

But any drop in the efficiency of the regenerator due to deposits there in the 10-day run doesn't bother the fuel rate at all because we recover those BTU's in the waste heat boiler. And, in the winter for example, we can't run much below 3,000 horsepower because then we will be short on steam and we need the steam for our ship's service generator set. The Chief Engineer, a steam turbine man originally, not now, has a Diesel standby generator set which is never logged. The only time I can tell that the generator set is run is about one or two hours a week, just to cover the regulations; but the big thing about it is that he doesn't want to run the Diesel generator set. He says it's too noisy.

MR. J. C. MILES, University of Illinois: I could stand clarification on your calculation of specific fuel consumption. You mentioned the boiler. It is included in the specific fuel calculations?

MR. JACKSON: Yes, it is. The only point I covered was total fuel used by the ship. The specific fuel consumption is based on the total fuel used by the ship and the horsepower output.

MR. MILES: You might think of it, then, in the light of over-all effectiveness as a regenerator plus a boiler, and it must really be quite high. The exhaust temperature from the boiler would be on the order of what?

MR. TANGERINI: About 470°.

CHAIRMAN GOLDSMITH: You have to figure the specific heat there, too, because of the excess air.

MR. JACKSON: That's right. The entering temperature to the boiler is 550°. There is a 100° drop through the boiler so that would be 100 degrees higher.

CHAIRMAN GOLDSMITH: I would like to call your attention to something else. I never had any experience operating a gas turbine. I have operated motor ships and designed them, and steamships, and high temperature ones. The rather remarkable thing here that I want to call to your attention is that these are the first ships where they were sure they knew what the horsepower was.

MR. JACKSON: Let me speak of that point a minute. The horsepower comes from trial data primarily, in which they did know the horsepower, and from data that Mr. Van Cott of the Maritime Admin-

istration have available. Mr. Van Cott thinks he has estimated his horsepower low.

MR. HORN: Have you had to increase your personnel in the engine room?

MR. JACKSON: No, we decreased it.

MR. HORN: What is your personnel now?

MR. TANGERINI: Twelve versus fifteen. Fifteen men were scheduled on the Liberty ship whereas the *Sergeant* carries twelve in the engine room.

MR. HORN: So you carry one extra for training, is that it?

MR. TANGERINI: That was to carry the regulars through their first vacation period. Every man has about two voyages and then he has to be dropped off and we have to train one man, and he was usually the second junior third. So that that fellow would have one voyage under his belt before he took over.

CHAIRMAN GOLDSMITH: What is the ratio of overtime?

MR. TANGERINI: About the same as all the other ships, about 40 per cent.

MR. FOSTER R. PEGG, Alco: I would like to know how you manage to operate this gas turbine somewhat below its maximum output and, at the same time, have maximum temperature?

MR. JACKSON: The gas turbine operates at the 6,000 horsepower point with an inlet temperature of 1450° and an exhaust temperature of 950°. As we increase the power output above that, we hold the 1450° inlet temperature but the exhaust temperature drops.

MR. PAGE: How?

MR. JACKSON: This is arranged in the control system and the variable angle nozzle permits the adjustment of energy between the two turbines so that this is possible.

Incidentally, the variable nozzle also permits the machine to be trimmed at all times, irrespective of any fouling that might occur. The ship can be kept up to temperature at the rated or any other horsepower by virture of having variable nozzles in the turbine. That has been a very essential feature in actually achieving this fuel rate.

MR. L. B. SANDBORN, Esso Research and Engineering: You mentioned that you have had the salt fouling problem. Has there been corrosion associated with this? And second, your treatment costs were quoted at 1¼ per cent of your fuel cost. Was this total treatment cost or only vanadium treatment?

MR. JACKSON: That was vanadium treatment, to answer your last question first. In addition, there is some emulsion treatment that adds a small additional amount. I don't remember just how much that is. It is not a great amount. The use, however, of fresh water in the washing system can be considered a charge, perhaps, and I don't know offhand what that amounts to.

MR. BRUCE BUCKLAND: I think your questioner is probably worried about an oil that may be heavy enough so that it requires addition of magnesium sulphate to wash. The oil that Mr. Jackson is talking about, as used on the ship to date, uses only fresh water to wash.

MR. JACKSON: To answer your first question, there has been no noticeable corrosion due to salt contamination, but the excessive accumulation of salt has been removed.

MR. MILES: I believe you quoted figures of reduction of power due to increased inlet pressure drop and increased exhaust back pressure. What are the penalties you have to take as a result of the regenerator and the waste heat boiler pressure drops?

MR. JACKSON: I don't recall saying anything about pressure drop. I don't remember what it is in the *Sergeant*. As a matter of fact, there is some pressure drop through the waste heat boiler. There is some pressure drop in the inlet drum. In general I can tell you, though, that power output is depreciated about 2½ per cent for each per cent of pressure drop in the intake system. It is depreciated about a per cent and a half for each per cent of pressure drop in the exhaust system. The difference between the two is the pressure drop in the inlet system.

MR. IRVIN: What do you consider as low vanadium fuel?

MR. JACKSON: Middle Eastern fuels typically run 50 parts per million of vanadium. Fuels from Venezuele, residual fuel which is normally available along our northeast coast, run some 300 parts per million. Fuels normally available on the Gulf Coast in the southern part of the country run 50 or 60 parts per million. Will you confirm that Mr. Buckland?

MR. BUCKLAND: There is no generally recognized, at least as far as I know, demarcation about the lowest residual vanadium residual. I have seen one from down around Corpus Christi about 10 parts per million. The highest I have seen was that which took place at Bangor, Maine. We had been running with about 340 parts of vanadium and the next batch of oil we got was about 420. Those are the highest I have ever seen.

MR. KREIG, Danham Chemical: You stated the unit was being washed after every voyage on the *Sergeant*. I would like to know why that is necessary after each voyage, and, if so, how much time is involved.

MR. JACKSON: Practically, I think, it is necessary, yes. It removes all the deposited ash throughout the machinery and also any salt contamination which may have occurred. It prevents any buildup. Now it is low enough so that it is hardly noticeable with a single sea passage. It might be with ultimate passages. Ash does build up on a turbine, and it requires removal to restore the plant to its clean condition. As far as the amount of time that is required, the Chief Engineer washes the plant in a total period of six or seven hours, of which most of the time is in cooling down. The total time in washing the plant is in the order of an hour or so.

CHAIRMAN GOLDSMITH: I would like to comment on that. I think you have to be fair to the gas turbine. I think the washing that has been done on the *Sergeant*, from what has been described, is less and takes less time than present-day washing on boilers, on steamships. I think you can confirm that if you talk to some of the operating people.

MR. KREIG: That may be true, but you don't do it every ten days.

CHAIRMAN GOLDSMITH: Yes, you do. I am sorry, but you do with the kind of fuels you get today. I say that as an oil man.

MR. PASSMAN: I think the experience that your Chief Engineer came across through his own initiative of washing is interesting. We conducted investigation at the U.S. Naval Engineering Experiment Station for washing and found that the best way to do it was to take a water hose just like that.

We tried a number of different ways, all different types of elements, and found that if you had to wash at full power, water doesn't do any good at all. You had to get into harder materials, solids. If you can afford to lower your power down to part-load operation, and still maintain operation, water would do a rather good job. But about 98 per cent was the best recovery you could get. By washing the way you described, with only moderate temperature water, fresh water, just pour it right through the unit, you are able to get full 100 per cent recovery repeatedly.

MR. SANDBORN: You placed considerable emphasis on the noise of these small units. What degree of attenuation did you achieve on these boats?

MR. CARLSON: I think it might be better to provide the comparison on tests that we have made in quiet areas on the Jupiter engine itself. Without silencing on a 10-foot radius sound level will run something between 95 to 100 decibels. With suitable silencing, we can drop that down to 88 decibles, which represents a lot of attenuation. And actually, your high frequencies are fairly easy to attenuate, and we silence them to the point where you can carry on a conversation immediately adjacent to the gas turbine packs.

Controllable pitch propeller installations on British frigates have recently been put through preliminary trials with highly satisfactory results. The 12-foot propellers are designed for 7200 SHP each. The blade pitch is changed by hydraulic actuator gear mounted on an inboard section of the shaft and coupled to the propeller through a mechanical valve rod and hydraulic tube running through the bore of the shaft. The actuator is controlled from the bridge by a pneumatic coupling, or locally by mechanical means. The operating gear is designed with a greater safety factor than the blade. Service so far has indicated that the blade can withstand considerable damage without damage to the operating mechanism. The pitch is designed to change to the full ahead position in the event of failure of the operating gear, so that engine speed control can then be used.

—from ENGINEERING
December, 1958

An accessory for detecting and amplifying radio signals with virtually no limitation caused by self-noise is in use on the fifty foot radio telescope at the Naval Research Laboratory. The device, called a "maser" (standing for microwave amplification by stimulated emission or radiation) contains as its central element a synthetic ruby, chilled to near-zero temperature in a bath of liquid helium, and other components of standard microwave equipment. Amplification noise, associated with streams of electrons boiling out of a cathode which add their own random variations to the signal imposed on the stream, is completely absent in a maser.

The maser operates on the principle that, if a quantum of energy (in this case, an incoming radio signal) interacts with an atom in an excited energy state, the atom will revert to a lower energy level, while emitting one or more quanta of enrgy at a characteristic frequency to add to, and thus amplify, the incoming signal. Repetition of this process carries out the amplification to the desired level. In the NRL maser, the chromium atoms in the ruby are excited to the high energy state by a "pumping" microwave, which is of different frequency from the incoming and amplified energy.

With the help of this amplifier, scientists hope to probe far beyond the presently achievable ranges of observation in space. Other uses of masers are projected for experiments in the general theory of relativity, for long distance communications and for super-sensitive magnetometers.

—from SCIENTIFIC AMERICAN
December, 1958

A new model basin is now in advanced stages of construction near Feltham, England. The facility consists principally of a 1300-foot long tank and a 100-foot square maneuvering basin. The towing tank will be equipped with a carriage capable of towing 5-ton models at speeds up to 50 feet per second. It will be equipped with a wave maker. Also included in the facility is a water tunnel intended for research on propellers. Model sizes up to 24 inches in diameter can be accommodated.

—from SHIPBUILDING EQUIPMENT
November, 1958

A bonding technique which has now graduated from the laboratory to the production line is the soldering of metals and metalloids by ultrasonic energy. This method of soldering, which uses conventional types of solder, does not require the use of flux, even in the presence of heavy oxide films or other surface coatings. This feature makes the method especially adaptable to the semi-conductor industry where the contamination of fluxes is often detrimental to transistor performance. Various tip sizes are provided for the equipment, each adaptable to hand operation or automation. Soldering spots as small as 0.002 inches, often required in transistor work, can be readily produced.

—from MILITARY ELECTRONICS
October, 1958

ROBIN S. HIGHAM

THE ROYAL NAVY'S FREAK SUBMARINE DESIGNS

THE AUTHOR

was born in England and educated in that country and in the United States. He served in the Royal Air Force as a pilot, 1943-1947. He attended the University of New Hampshire and graduated cum laude *from Harvard in 1950. After graduation he taught at the Webb School of California, 1950-52 and took an M.A. at the Claremont Graduate School. Did graduate work at Harvard, 1952-54, and assisted Prof. Robert G. Albion. Taught at the University of Massachusetts, 1954-57, and at the University of North Carolina since that date. He obtained Ph.D. in History from Harvard, 1957. He is the author of "The Port of Boston and the Embargo, 1807-1809," THE AMERICAN NEPTUNE, July 1956; "Pioneer British Airlines in West Africa," ESSO AIR WORLD, 1958. His Ph.D. dissertation was on the development of British overseas airlines, 1918-1939/40. He has a manuscript in progress on British rigid airships.*

STEAM-TURBINE propulsion, underwater missile launching, and aircraft carrying submarines are much in the news today. Atomic *Nautilus*, Polaris-firing submarines, and Snark-launching *Halibut* are not entirely new. Back in the years 1915-1932 the Royal Navy operated a collection of submarines with similar, though much less advanced, features.

The *K*-class were oil-fired steam-turbine boats designed for Fleet operations. The *M*-class monitor submarines were *K*'s redesigned from the keel up to carry a 12-inch gun and later converted to aircraft-carriers and minelayers. The third class remained unique in the Royal Navy, though imitated by the French. *X-1* was the only twin-turret commerce-raiding submarine built, and the only one of the group whose design was based upon German U-boats surrendered at the end of the War in 1918. Nevertheless *X-1*, like the *M's* was a product of the recommendations of the Submarine Development Committee of 1915.

As it became clear that Britain did not have all the submarine types necessary for the new three-dimensional naval warfare, the Admiralty, then under the direction of Winston Churchill and Lord Fisher, called for new designs. So many plans were submitted that the Submarine Development Committee was created to handle the problem. This body grouped designs into six basic categories: coastal, patrol, Fleet, cruiser, minelaying, and monitor submarines. Since by then the *K's* were already under construction, as were some modified patrol minelayers, the Committee's contribution to new designs lies essentially in the field of monitor and cruiser submersibles. The former was realized in the *M*-class and the latter in the post-war *X-1*.

The steam-driven Fleet submarines were an attempt to create a tactical weapon capable of flotilla use in conjunction with the Grand Fleet. They were specifically designed for the North Sea and it was not contemplated that they would be called upon to operate in less sheltered waters. The lessons of Jutland made the battle fleet even more anxious to

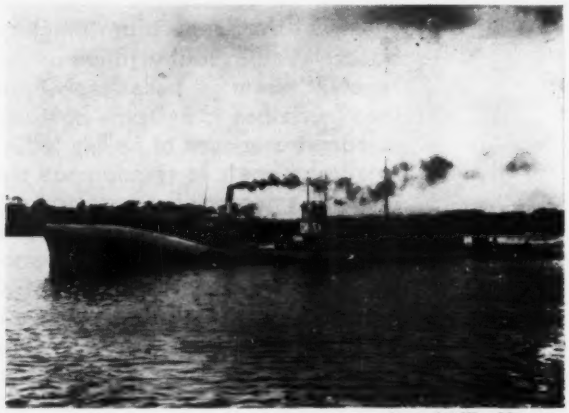
obtain the tactical protection in rearguard actions which Scheer was thought to have had. With their 24-knots speed the *K's* could keep pace with the fleet. If it had to retreat, they would submerge to provide an ambush in which to delay or cripple the enemy pursuit. However, with the refusal of the High Seas Fleet to expose itself, they became obsolescent. Later attempts to use them in the Atlantic proved fatal.

The *M*-class were originally *K's,* but they were redesigned immediately after the keel-plates were laid. The Submarine Development Committee thought a 12-inch gun vessel could be used in the North Sea to obtain tactical surprise against surface ships. It would also be a difficult target for shore guns if used as a monitor. In addition, Lord Fisher argued that with the then 24-knot torpedo, chances of success at more than 1,000 yards were negligible. Therefore, a large-gun vessel would have a considerable advantage both as to range and tactical surprise. Of the four M's originally ordered, only three were completed. Only *M-1* was operational before the war ended, and, as the Admiralty were afraid the Germans might make effective use of the idea, she was sent to the Mediterranean.

The products of wartime ingenuity, the *K's* and *M's* were kept secret until after the war. *X-1* remained throughout her career wrapped in official shrouds to such an extent that even the authorities disagree on her length. *Brassey's* claiming 363 feet and *Jane's* 350.

X-1 was built as a cruiser submarine after the end of the war when the "long-range group" managed temporarily to persuade the Admiralty that Britain needed to fulfill the 1915 recommendations. After all the Germans had made conspicuous use of their cruiser submarines. But by the time she was commissioned in the mid-twenties, *X-1* had many enemies with plausible arguments. Except for possible operations against Japan or the United States, Britain was still most likely to fight her submarines in the relatively shallow Mediterranean, North and Baltic Seas. There the H-class and other similarly small boats could operate successfully, while a 3600-tonner like *X-1* might be too obvious to achieve her ends. *X-1,* as her designation indicates, was really an experimental boat. If she had not suffered from chronic engine trouble, she might have made some notable voyages as her 450 tons of fuel gave a radius of action of 12,500 miles.

In 1914 Britain had two experimental high-speed submarines building, the Diesel-engined *Nautilus* and the steam-driven *Swordfish*. The former was designed for 17 and the latter for 19 knots. But as it was soon realized that these boats could not keep up with the fleet, the 19-knot *J*-class was designed. As these, too, failed to answer, Sir Arthur John, Director of Naval Construction at the Admiralty, designed a radically new boat. The *K*-class were designed as the Grand Fleet wanted them with a surface speed of 23-knots and the ability to dive in five minutes. So good was Sir Arthur's design that the *K's* went into production without a prototype being tested.



Imperial War Museum

K-7: Laid down in 1916, she was modified in the bow to cope with the short chop of the North Sea when going at speed on the surface. She may have been built by Vickers.

Seventeen boats were completed. Four others were converted to *M*-class; one *(K-26),* when completed, was larger than the others, and a number of the twenty-seven originally laid down were never finished. *K-13* sank on trials, was raised and renumbered *22*. With an overall length of 339′, extreme beam of 26′ 6″ and depth of 19′ 4″ they displaced 1,980 tons on the surface and 2,560 submerged. Each boat had five different power plants. Two sets of oil-fired Yarrow small-tube boilers provided steam for a pair of single reduction Parsons or Brown—Curtis turbines giving 10,500 s.h.p. and a surface speed of 24 knots. An 800 h.p. Diesel was provided for quick diving, getting underway upon surfacing and cruising. Since they were expected to operate with the Fleet, the *K's* were allowed four minutes to submerge when doing 20 knots. This was not excessive since the funnels had to be folded back, the draft fans shut off, steam blown off, and the large number of hatches closed.

For submerged operations an electric transmission was used. (According to the 1919 *Brassey's,* the *K's* were one of the first classes of British submarines in which electric propulsion was successfully installed.) In addition electric motors operated the funnels and opened and closed hatches. There was an air compressor and hydraulic power was provided for the operation of the hydroplanes, periscopes and wireless masts. The thirty-foot periscopes were the longest which had yet been made in Britain at the time of their installation.

Armament was varied. All of the class carried one or two 4-inch guns and one 3-inch A.A. gun and

eight or twelve torpedo tubes. Four of the latter were mounted above the hull in the superstructure and could be fired abeam. In 1918 some of these beam tubes were removed and depth-charge throwers installed so that these boats could be used for anti-submarine work. Deck armament varied somewhat; *K-17* carried a 5.5-inch H.A. in place of her 3-inch A.A. gun. For all the class the normal complement was 54 officers and men.

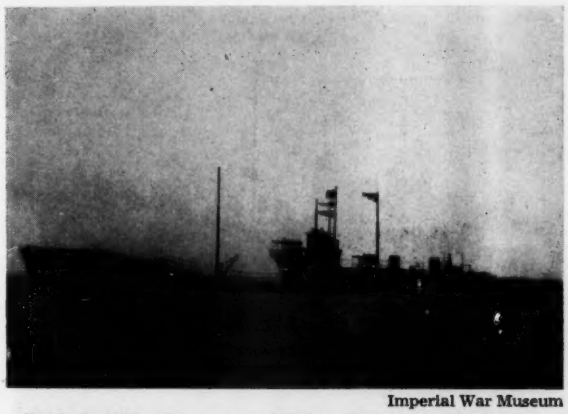
K-1, which had the honor of being inspected by King George V on his visit to Scapa Flow in late 1916, was lost by collision in the North Sea on 18 January 1917. *K-4*, *K-6*, *K-9*, *K-14*, *K-17*, and *K-22* (ex-*13*) were all involved in the May Island disaster.

In January 1918 the plans were promulgated for a sweep to the Norwegian coast in the hopes of bringing the Germans to sea. The operation called for the Twelfth and Thirteenth Flotillas each to supply five *K's* to accompany the fleet. The ships left Rosyth late in the afternoon of the 31st. In the darkness off May Island in the mouth of the Firth of Forth a series of collisions occurred. Exactly why has never been explained. It appears that *K-22* suddenly sheered out of line under full helm and struck *K-14* a severe blow. Five minutes later the latter unfortunate was bumped by the Iron Duke class battleship H.M.S. *Marlborough*. Meanwhile *K-17* had stopped to stand by her sister ships. H.M.S. *Fearless*, the light cruiser assigned as flotilla leader, who was following the battle squadron, then cut *K-17* in half. *K-4* hauled out of line to avoid *Fearless* and also came to a stop. Whereupon she was rammed and sunk by *K-6*. *K-9* was also damaged before order was restored. Of the ten *K's* which started the operation, two were sunk, and four had to return to base for repairs.

K-13 foundered in Gareloch on 29 January 1917 while on builder's trials owing to diving before all the hatches were closed. She was raised after 54½ hours and food and air passed in and 42 men rescued. A gale then forced the salvage vessel to let her stern drop again before the other 31 could be gotten out. However, she was later raised and renumbered *K-22* and as such was present at May Island on 31 January 1918.

Imperial War Museum

K-8: Making speed trials in Gareloch. Note unmodified bow.



Imperial War Museum

K-12: Built by Armstrong-Whitworth in 1917. She is a good example of the variations in the class. Note special gun-mounting forward of the conning tower and permanently screened navigating bridge. Behind the after gun are the two funnels, which were retracted when she submerged.

K-5 was part of a post-war flotilla operating with the Atlantic Fleet. On 20 January 1921 she failed to resurface after an exercise in the Atlantic. As she went down in 500 fathoms, it has never been possible to know exactly why she foundered. But writing in the London *Times* at the time, Rear-Admiral S. S. Hall, who was commander-in-chief of British submarines during World War I, pointed to a number of probable causes.

The K-class had been designed for the North Sea. Despite the addition of elevated forecastles, they were wet boats and the danger of flooding was a constant worry to their commanders in bad weather. In order to attain high speed they were much longer than other submarines of their day, and this, coupled with the voice-pipe and telephone system of relaying orders to the vent-tank operators, buoyancy tanks being spread over 300 feet, meant that they required "an exceptionally well-trained crew." This *K-5* did not have. She had just taken on a new crew, as well as a new first lieutenant and two officers who had just joined their first submarine.

Some naval officers at the time thought she may have had her hull ruptured by an internal explosion while diving. It appears more likely, however, that either a hatch was left open or that she got out of control with a green crew and was crushed before equilibrium could be restored. Admiral Hall, in fact, criticized the Admiralty for ordering these vessels into the wintertime Atlantic in the first place, feeling that this may have led to difficulties.

As a result of the loss of *K-5*, the *K's* were withdrawn from the Atlantic Fleet and used in home waters. They were replaced by the less-complicated *L* and *M* classes. In June 1921 there were twelve of

Imperial War Museum

Unlucky K-15. Built by Scott; she sank twice.

the steam-driven boats left including the latest, *K-26*, which had just been delivered by Vickers. All but one of these were paid off by the end of 1925 and soon sent to the scrapheap.

Meanwhile *K-15* sprang a leak. During the night of 27 June 1921 she slowly settled by the bows, while moored alongside H.M.S. *Canterbury*, a *Cambrian*-class light cruiser. An alert sentry looking over the cruiser's side realized the position. He leaped aboard awakened the 5-man harbor watch asleep below, and they all escaped to *Canterbury* in the nick of time. Ten days later the submariners at Portsmouth successfully raised her by closing all the vents and pumping air into her from another submarine. She was lost a second time in Plymouth Harbor in July 1923.

K-2, *K-6*, *K-7*, *K-8*, *K-9*, *K-10*, *K-11*, *K-13*, *K-14*, *K-16*, and *K-22* were all scrapped in the 1925/26 program. *K-1* and *K-12* were lost in the North Sea; *K-4* and *K-17* off May Island; *K-13* was renumbered; and *K-5* and *K-15* were peacetime casualties. Only *K-26* was retained in service after 1925.

K-26 was not completed until 1921 and can really be regarded as belonging to a new class. She incorporated a better streamlined forecastle, permanently shielded bridge, was 12 feet longer and 18″ wider as well as heavier than the original *K's*. As a result she displaced 2,140 tons on the surface and 2,770 submerged. She carried two 4-inch and a 3-inch A.A. gun and two Lewis machine guns. She was begun by Vickers in July 1918 and launched in August 1919, and was then towed to the Chatham Naval Dockyard to be completed. While there three men were injured when testing the safety valves. Although orders called for the boiler compartment to be cleared when diving, men were in there as she was still alongside. Over 235 p.s.i. pressure having been reached, the valve lifted, steam hit the deflector and filled the compartment scalding the men. Owing to the cramped space and the need for hatches being closed for diving, there was no outside steam vent, but they had failed to realize this.

K-26 was finally commissioned at the end of 1923 and left early in January 1924 for a memorable cruise. In the course of her voyage she covered 20,000 miles without a mother ship. Being able to carry 300 tons of fuel, she had an extended range and sufficient stores for long endurance. She called at Port Said, Aden, Bombay, Colombo, and Singapore, and returned to Portsmouth in August 1924. The trip proved that steam-driven submarines were habitable in the Tropics, even passing down the Red Sea. After a refit she was attached to the Mediterranean Fleet, but later, in company with *X-1*, detached as a separate command. Placed in the reserve in 1930, she was subsequently scrapped.

K-18 and *K-19* were originally ordered from Vickers and *K-20* and *K-21* from Armstrong-Whitworth. Almost immediately the design was changed and these four were converted to Diesel-powered monitors. *K-18* became *M-1* and was the only one to see wartime service. *M-4* was cancelled. However, for six years Britain had three of these unique boats in commission.

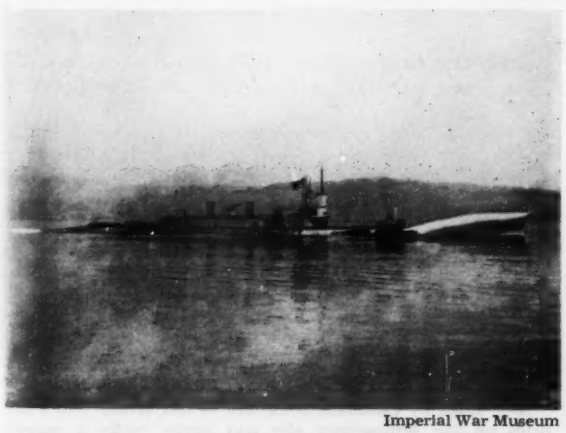
With a surface displacement of 1,540 tons and a submerged of 1,940, they were smaller than the *K's*. 295′ 7″ long, 24′ 7″ in beam and with a depth of 18′ 6″ they could do 16 knots surfaced and 10 knots submerged. Each was powered by two sets of 12-cylinder Diesels developing 2400 s.h.p., and electric motors of 1600 s.h.p. for submerged operations. 76 tons of fuel and a crew of 60 were carried. They were armed with four 18″ torpedo tubes and a 3″ A.A. gun. But their outstanding feature was their main armament.

Each mounted a 12-inch 35 caliber gun weighing 60 tons taken from one of the old *Majestic*-class battleships. In each boat these were fitted with hydraulic machinery enabling them to be loaded, elevated and fired from inside the hull. Attack technique was to cruise at periscope depth until the target had been lined-up in the sights with a small time allowance made to bring the boat to firing depth. The gun was elevated to about 45-degrees. Twenty-five seconds elapsed after the order being given before the boat rose to firing position. Then the needle sight on the gun muzzle could be lined up by periscope and the gun fired with only about six feet of the barrel above water. The muzzle had to remain surfaced for fifteen seconds after firing to clear the barrel of smoldering particles. The muzzle tampion then closed and the boat slid back to the depths to reload. The original tampions did not prove entirely effective and a hydraulically-operated design was fitted in their place in 1923.

The "Mutton Boats," as they were nicknamed because of the likeness of their gun mounting-conning tower to a leg of lamb, had one great advantage as monitors. They presented a minimum target to shore batteries, which tended to outrange the earlier surface gun-carriers.

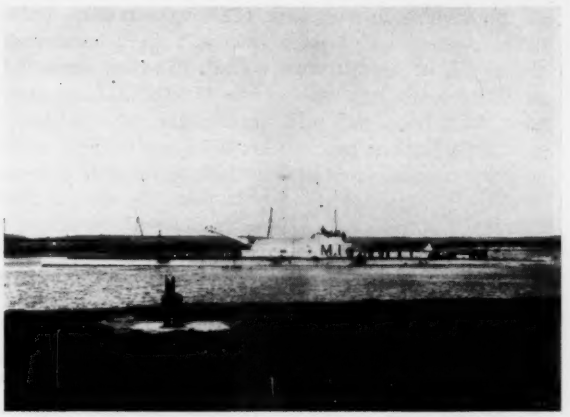
M-1 was first commanded by Max Horton, later famous as Admiral commanding Submarines and later Western Approaches in World War II. After commissioning, *M-1* was sent to the Mediterranean. Shortly after the war she was seen in Constantinople. Later, she and her sisterships were sent to the Atlantic fleet to replace the *K's* after the loss of *K-5* in 1921. In August 1924 they were withdrawn to the half-flotilla attached to H.M.S. *Dolphin,* Fort Blockhouse, Portsmouth. In 1925, after refit, the *M's* were included in the Fifth Flotilla for North Sea and other exercises. They were well-liked boats and regarded, despite their monstrous armament, as the most stable British submarines of their day. It was found that the weight of their guns helped start a dive, while as they reached twenty feet down the buoyancy of the housing had a levelling off effect which was much appreciated. They might never have become well-known if two of them had not had the misfortune to sink in the English Channel.

M-1 was the first. She left Portsmouth on Monday 9 November 1925 in company with other submarines bound for Gibraltar. Rough weather forced the flotilla to seek haven in Plymouth and Portland harbors. The Fifth Flotilla then decided to exercise its boats in Start Bay before proceeding. The weather was bad. Oblivious to the fact that submarines were exercising, a number of steamers were butting and pitching their way through the area. *M-1* was last seen to submerge some fifteen miles south of Start Point on Friday morning. A search was laid on. But the area was strewn with old wrecks from both war and peace. Eventually all of these were eliminated and *M-1* located. German divers, with new pressure suits allowing a descent to the 37-fathoms in which the boat lay, were rushed over in H.M.S. (D.D.) *Wolfhound.* But heavy currents in Start Bay made the operation most difficult. Then an oil slick was discovered some ten to twelve miles from the wreck



Imperial War Museum

K-16: Built by Beardmore in 1917 and scrapped in the 1925-26 program. Like K-15, she had taller funnels than others of the class. The crew clustered aft help indicate her destroyer-like size.



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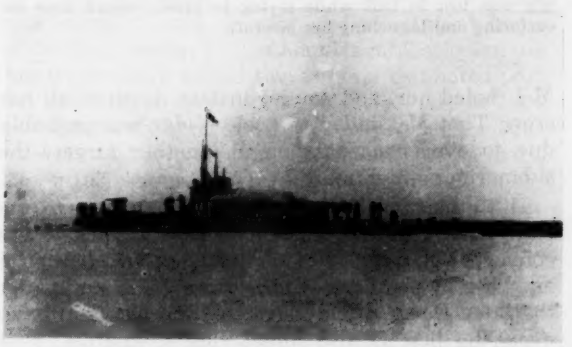
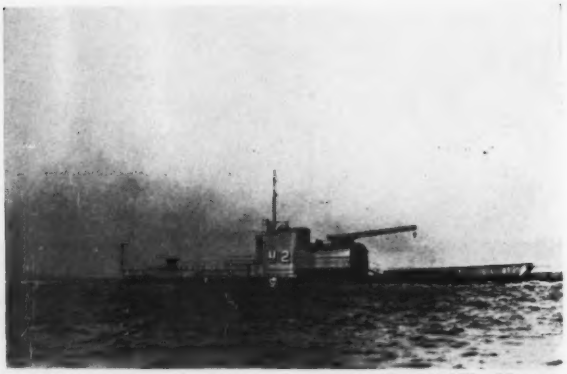


Imperial War Museum

"Mutton Boat" M-1: (Above) Leaving Vickers in 1918 before being sent to the Mediterranean. Armed with a 12-inch rifle and a 3-inch A.A. gun, she was the first of a surprise class designed in part to overcome the tactical disadvantages of 24-knot torpedoes. She was sunk by a Swedish collier while on submerged exercises in 1925. (Lower) M-1 in Royal Navy livery of the early 1920's after she had returned to the Home station.

then being investigated. Doubts arose once more as to the location of the missing boat.

Not until ten days after *M-1* disappeared did the master of the Swedish collier *Vidar* read in a Kiel newspaper of her loss. He at once contacted his owners, who reported to the Admiralty. At 7:45 hours on the morning of Friday the 13th the officers on *Vidar's* bridge felt a bump which they took to be a mine. They gave thanks when a second bump under the stern also failed to bring an explosion. After that they thought no more about it until they saw the news at Kiel. When *Vidar* reached home, the Swedish government ordered her drydocked. Government inspectors accompanied by the British naval attaché examined her hull and found the forward part bent in and the stern out of line. In each place were smears of grey-green paint. This was analyzed and found to be the same as had recently been used on *M-1.* The obvious conclusion was that *Vidar,* loaded with coal and pitching heavily had crashed on to



Imperial War Museum

M-2: As modified in 1927 to carry Parnell Peto aircraft. Note derrick on hangar roof and catapult on the foredeck. She was lost in 1932 while trying to break record time for surfacing and launching her aircraft.

M-1, holed her, and caused instant death to all her crew. That *M-1* failed to avoid *Vidar* was probably due to over concentration on another target—the submariner's nightmare.

The other two *M's* were now withdrawn to the experimental half flotilla at Portsmouth. *M-3* was converted about 1927 to a minelayer, which lengthened her by eight feet, and became the prototype for the later *Rorqual* and *Narwhal*. She was not, however, the first British minelaying submarine. *E-41* had laid mines in the German or Heligoland Bight on 22 June 1916. But *M-3* had a much larger capacity as her rails ran for two-thirds of her length on top of the hull. As a result of this change she gave the impression of going backwards since she still had the original low *K*-class bow! After serving for a number of years, she was scrapped about 1931.

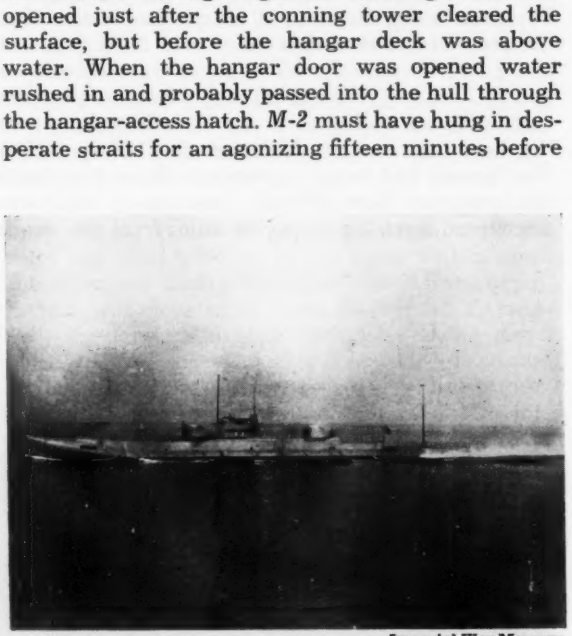
During the First World War British submarines had had considerable trouble with Zeppelins. In an attempt to overcome this obstructionism, *E-22* had taken a small fighter into Heligoland Bight. But as the aircraft could only take off on calm days and was lost when the submarine was forced to submerge, this was not a success. The idea of coupling aircraft and submarines did, however, persist. The U.S.N. tried it out on an *S*-class in 1923.

In 1927 *M-2* was rebuilt as a submarine aircraft-carrier. The 12" gun was removed, the housing converted into a hangar, and a catapault laid out on the deck forward of the old gunmount. Parnall and Co., of Bristol designed and built a small two-seater scout biplane for use in the new vessel. When returned to service she looked rather like a forerunner of *Halibut*.

On 26 January *M-2* proceeded from Portland to her exclusive exercising area west of the Bill. She dived at 10:30 a.m. and was never heard from again. Once more, as with *M-1*, this was an area strewn with wrecks. At first *M-2* was thought to have been located, but then new evidence including oil and tappings caused doubts. Not until the 29th was a casual conversation between a collier captain and a Portland clerk forwarded to the Admiralty. At the time of the conversation the merchant skipper had asked if it was not rather unusual to see a submarine submerging stern first? In making his report, *Tynesider's* captain said that at 11:15 a.m. he had seen *M-2* bows up and settling so that the number on the conning tower was only half visible. At 11:30 she had slid below stern first.

This information, coupled with a fishing smack's report of flares and explosions, caused the search to be moved some seven miles further west. By now *M-2's* 48-hour endurance was exhausted. As at Start Bay, the currents prevented divers going down to examine objects snared on sweep wires. (How different was the search for H.M.S. *Affray* just a few years ago. Then a television camera was lowered and the officer in charge of the search, watching the screen in his cabin, confirmed the wreck before the divers could reach her.) *M-2* was not in the end located until the evening of 3 February. The wreck was buoyed and the possibilities of salvage investigated.

When divers finally got down to her they found the upper conning tower hatch open as well as the hangar door. It was believed that an attempt was being made to cut down the time taken for launching the aircraft. Through eagerness the hangar door was opened just after the conning tower cleared the surface, but before the hangar deck was above water. When the hangar door was opened water rushed in and probably passed into the hull through the hangar-access hatch. *M-2* must have hung in desperate straits for an agonizing fifteen minutes before



Imperial War Museum

X-1: Built by Chatham Dockyard to test World War I theories on big submarines, she was never really a success. Plagued by temperamental engines and hostile service critics, she was scrapped before World War II. With a surface displacement of over 2700 tons, she was one of the largest submarines ever built.

Imperial War Museum

K-26: Built by Vickers in 1919-1921, she was the last of her class. Incorporating modifications developed from experience with the original boats, she was larger and capable of long-range cruising. Note gun-tube and improved bow and forecastle.

settling between two old wrecks in some 18 fathoms; there her crew may have lived for some hours afterwards.

Throughout 1932 salvage efforts were conducted. Some 51 divers were at one time employed in sealing the hull with steel plates and hydraulic concrete. Mr. Cox, who had been engaged in raising the Germans at Scapa Flow, took charge. On his advice the boat was left until June when more moderate weather was to be expected. In July she was pumped full of air and camels attached. But after the bow had risen 18′, divers discovered one of the torpedo tubes was leaking and she was lowered again. In September she was once more ready and came to within 18 feet of the surface, but a gale came up and one of the camels broke loose. A final effort was made in December. But after the stern shot to the surface and the bow sank again to the bottom, the efforts were abandoned.

The last of the Royal Navy's inter-war experiments was *X-1*. Begun on 1 November 1921, she was completed in January 1924 and commissioned on 25 September 1925. She was such a "hush-hush" ship that even by 1929 *Jane's* was unable to fill in all the normal details. It was known that she cost about £1,044,158 with alterations. She displaced 2,780 tons on the surface and 3,600 submerged and had a surface speed of 19½ knots. Submerged she could do 9 knots. Such a large ship required a much bigger crew than even the 60-70 of the *M's*. *X-1* had 110 officers and men. She carried six 21″ torpedo tubes and two machine guns in addition to her main armament. This consisted of four 5.2″ guns mounted in twin turrets.

Additional features were a reported ability to remain submerged for two and a half days, an extremely small turning circle, and an especially strengthened hull for deep diving.

It is not surprising that such a large and complicated vessel should develop defects. Initial trials resulted in a return to Chatham Naval Dockyard for alterations which raised the original estimated cost from £840,000 to over £1,000,000. Trials late in 1924 were apparently considered successful, and the 350-foot *X-1* was delivered to Portsmouth in January 1925. In 1926 she ran out to Gibraltar and back alone. Later she was attached to the Mediterranean Fleet and then made an independent command. She was said to be an uncomfortable boat in hot weather.

Though she incorporated all the latest technology gained from a study of the surrendered U-boats, she does not appear to have been an unqualified success. Her career was short, perhaps because she was so large.* At any rate, by the end of 1930 she was in mothballs at Chatham. By mid-1932 she was the only one of the "freaks," as Admiral Hall called them, left on the roster and was scrapped before the war.

If all of these submarines were unusual, they have ceased to remain unique types. Whether they were "freaks" or forerunners, they were notable attempts to deal with problems we have not finished solving today.

*X-1 was exceeded in size by the French *Surcouf* of 2,880/4,304 tons. The latter was 361x29½x23½ feet and carried two 8-inch guns, a small seaplane and 10 21.7-inch torpedo tubes. However, she was not laid down until 1929 and not commissioned until 1934.

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.
Service to God and Country is our special privilege. We serve with honor.

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The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

"JOURNAL OF THE FRANKLIN INSTITUTE"

PLASTICS IN THE SPACE AGE

ACKNOWLEDGEMENT

John H. Lux, President of Haveg Industries, Inc., Wilmington, Delaware, is the author of this article which appeared in the July 1958 issue of the "Journal of The Franklin Institute."

On October 4, 1957, our radios told us that the Russians had ushered in the Space Age with the first satellite. We all knew it was coming, but we didn't expect it so soon, nor did we expect to find ourselves behind in the "Space Race."

This has required all of us to evaluate our own future contributions so that we can do everything possible to obtain a lead in the near future. We feel that the plastic industry will make major contributions to the "Space Age."

Because of the widespread use of plastics in every phase of our life, many people have suggested we were in the Plastic Age. We have plastics in clothing, automobiles, homes, appliances and food packaging. The word "plastics" brings many different images to peoples' minds, yet to 99 people in a 100, plastics means plates, drinking glasses, toothbrush handles, automobile trim, kitchen work surfaces, toys, or swimming pools. These products have emerged from the laboratories in recent years and are providing us with new and useful items, many of which we never enjoyed before. Plastics in the coming "Space Age" will multiply this list and add many more items and uses, some of which are beyond the scope of our present thinking.

Let's look at the demands of the future. First, there will be a demand for versatile materials of construction for making huge structures which are lighter in weight, unaffected by the elements, easy to handle, transparent or translucent. Second, there will be a demand for materials to operate at temperatures lower than those now generally utilized. Third, there will be a demand for materials to withstand the high temperatures—25,000° F and perhaps higher. Fourth, there will be a demand for materials which will be expected to stand the high erosion of re-entry and the stress and strains of speeds of high Mach numbers. Fifth, products will be needed for electronic applications with a wide variety of electrical, magnetic and transistor properties. Sixth, there will be a demand for materials which will be able to withstand the nuclear radiation, cosmic rays and other problems encountered in space travel. Seventh, we will need plastics which will provide large amounts of energy through combustion or other chemical reactions for propulsion.

Many of these properties are now available to a wide degree in plastic materials but we look forward to vast improvements in the future.

Before looking at plastics, let's look at why the other materials are unsatisfactory under the above conditions. In the high temperature and high velocity field (areas above 2000° F and speeds over Mach 1) most people felt that the answer to high temperature materials of construction had the best possibility of coming from such structures as metals, metal car-

bides, graphite or ceramics. With respect to metals, the thermal conductivity is so high that the metals very quickly reach the temperature at which they lose strength and even melt or flow. Sometimes this happens as quickly as a few parts of a second, particularly above 3000° F, so that above this temperature metals are not practical. In the case of carbides or graphite, these materials at similar high temperatures are subject to oxidation in an oxidizing atmosphere and are also subject to reduction in a reducing atmosphere. Carbides and graphite also have a very high thermal conductivity and both of these materials are subject to serious limitations as far as fabrication techniques are concerned. No large structure can be made without great difficulty and there are limitations as to the strength of even smaller structures. In the case of ceramics, these materials are subject to shock so that in going from room temperatures to 5000° F in a matter of a second or less, these materials are subject to cracking.

In contrast to this, plastic materials and their derivatives have resistance to oxidation and reduction, good thermal insulating qualities, ability to withstand shock, ease of production by a wide variety of techniques, so that they can be fabricated from ¼ ounce up to 50,000 pounds and will operate permanently at temperatures up to 550° F, they will operate for thousands of hours in the 600-700° F range and at lesser times up to 18,000 or 20,000° F. As a result, in the high temperature field, it has been possible to make such materials of construction into blast tubes, re-entry nose cones for missiles, columns, 6000° F heat insulation, heat exchangers, nozzles, aerodynamic fins, missile jet fins, jet stabilizing rods and many other thermal structural components for aircraft, rockets, missiles and atomic energy processes.

In the nuclear field, plastic thermosetting materials have been tested at 10^{10} roentgens for periods of several months and an examination of test samples showed their strength doubled over a period of one year. These are now used in equipment for uranium refining.

In the field of polyethylene resins, it has been found that radiation causes a change in structure which will allow the use of polyethylene to be upgraded from around 130° F to temperatures above the boiling point of water so they can be sterilized, thus opening up broad new uses.

In the low temperature field, the use of Teflon and Silicone rubber products enables us to produce materials which will operate at —40° and —60° F and still retain the ability to withstand shock and not be subjected to fatigue as would metals. The silicone polymer oils provide lubrication as low as —60° F.

The reinforced polyester plastics were chosen for the large structures to house the DEW line, early warning radar system for use near the Arctic Circle, because of their ease of assembly, light weight, superior insulating and electrical properties. Many future structures, homes, factories, automobiles, aircraft, and auditoriums will soon burst forth in this versatile combination of plastics and fiberglass.

In the electronic field, Teflon coated wire makes it possible to engineer missile systems which will operate at high temperatures. It also enables computers and other delicate equipment to be built to operate at temperatures which would degrade most insulations.

These things have not been necessary in radios, television and other products because it is easy to call a repair man for a few dollars and replace any defective system. However, as one man has put it: "At 20,000 ft. or 20 miles up there are no repair men." Teflon-coated wire can be welded because in decomposition it does not form carbon particles which would set up conducting points. In the electronic area the use of plastic radomes, electrical terminal insulators, various complex electronic equipment, coaxial cabling and many other items are fabricated from plastics.

The guidance and control system of the missile represents about 50 per cent of its cost (but only 10 per cent of the weight), and it is here that plastics really offer advantages. Plastics are used to make the printed circuits, in eliminating metal parts, for potting and impregnation, and protection of wire and electronic components. In the mechanical missile components area there is a wide variety of cams, gears, levers and structural assemblies. In the manufacturing processes, plastics are ideal for tooling, since design changes can be made more quickly and at lower cost than with steel tooling.

Plastic foams, fillers and honeycomb are used in sandwich type construction to provide stronger units. Many metal units, such as the Martin Matador (B-61) are assembled using plastic adhesives. The number of uses of plastic coatings, sealers and liners on other materials will be broadened considerably as new materials are developed.

Also, another feature of the "Space Age" will be more difficult corrosion problems in the manufacture and handling of materials in the future. Plastics, unlike metals, do not corrode, so that they can be made to handle such violent materials as hydrofluoric, hydrochloric and sulfuric acids; strong caustics, chlorine dioxide, aqua regia and chlorine gas. The preparation of uranium, columbium, molybdenum, tungsten and tantalum for "Space-Age" use, uses large amounts of plastic equipment.

The development of plastics for the uses of the past and improvements for the future comes about only through the expenditure of a considerable amount of money and technical effort. This does not mean, however, that only large firms can play a significant role in the plastics industry.

My own firm, Haveg Industries, Inc., is a small company, working with plastics since the early 1930's. We have concentrated on solving over one

million corrosion problems in the last 25 years, and we have a number of firsts in the industry to our credit: (1) the first plastic pipe (some 25 years ago); (2) the first plastic fittings and valves; (3) the first chemically welded field systems; (4) the first plastic tanks (up to 35,000 gallons); and (5) the world's largest plastic structure, a fume stack weighing 42,000 pounds.

Using over thirty different plastic combinations, we manufacture thousands of items such as tanks, hoods, fume ducts, heat exchangers, cooling towers, reaction vessels, filters, steam jet ejectors, drying trays, electroplating tanks, bifurcators, pumps, rolls, corrosion resistant cements and tank trucks.

It was this background in plastics that caused Haveg to initiate work in the high temperature field many years ago. We felt that plastics were usable at temperatures of 5000° F, for short periods of time—and we proved it in actual rocket-firing tests. Our proprietary materials known as Rocketon, Missileon, Mercuron, Planeton, Galaxon and Asteron for high temperature applications find use in blast tubes, nose cones, nozzles, jet vanes, tail cones, insulators and adaptors. In addition to these fabricated materials, we also produce Siltemp glass which is available in both a sheet form and in glass rovings. This material is stable at 1800-2000° F, for use as an ingredient in many military projects and for solving many high temperature problems. Materials can be fabricated for short term use and insulation up to 6000° F. The latter products are usable in areas needing high resistance to erosion.

One of the most outstanding contributions of plastics to our future in the "Space Age" is that of furnishing the energy for our solid propellant type missiles. This field, pioneered by Thiokol Chemical Corporation, has changed rocketry from a "hit and miss" proposition to a field of high reliability. The use of plastics and an oxidizer such as ammonium perchlorate provides good combustion properties, ease of handling, high strength, and ability to work between —40° and +160° F. Among the plastics which are used are polysulfides, polyethylene, epoxy, vinyl, polyurethanes and various synthetic rubbers.

It is obvious that plastics are able to provide the entire missile system with the exception of the wiring and oxidizer; and plastics have been used in the manufacture of both of these.

We have shown you some of the areas of plastics in our future, a future in which even a small organization can play a very significant part and in doing so, can multiply its business from that of a small business to a recognized growth industry in the short period of two to three years.

A new type of self-righting lifeboat has resulted from five years of development by the Royal National Lifeboat Institution. The boat is designed to right itself from a capsized position in about six seconds. This is achieved by speedy transfer of most of 1½ tons of water ballast from a tank below the engine to a port side tank. The water flows through two trunks opened by pendulum operated valves when heel exceeds 110°. The boat is basically designed for coastal lifesaving service, and is thus required to be light weight for beach handling, but rugged for work in the surf. Power is provided by twin 43 bhp diesel engines.

—from ENGINEER
December, 1958

In diving operations, the length of time which must be spent by a diver in ascent, in order to provide a satisfactory decompression rate, has long been a problem. For example, a diver working for one hour at 100 feet requires an ascent time of 42 minutes. This time increases to 124 minutes for one hour at 200 feet. This large non-productive time contributes heavily to the expense and inefficiency of underwater work. In order to improve this situation, a submersible diving chamber has been used. The small chamber, carrying an attendant, is submerged to some intermediate depth, where it receives the diver when he is ready to ascend. Keeping the pressure in the chamber constant at the desired value, this mobile chamber can then be surfaced, freeing the tending crew to provide support to another diver while the first is undergoing decompression.

Because of the cramped quarters in the necessarily small submersible chamber, it has been the practice to transfer the diver to a conventional recompression chamber. This involves a rapid decompression and recompression for both the diver and the attendant, who must remain with him during the decompression process. This procedure, while normally successful, is not without some element of danger. For this reason, the use of the submersible diving chamber has not been universally accepted.

A recently designed submersible chamber removes the danger by eliminating the necessity for the intermediate decompression. The small submersible unit can be attached to the large recompression chamber with a pressure seal so that access between the units is possible at any desired pressure, allowing transfer of the diver without prior decompression. Thus the whole process from deep water to the relatively comfortable recompression chamber can be carried out expeditiously and with a minimum of danger. The submersible chamber can be rapidly made available for continuing operations.

—from SHIPBUILDING EQUIPMENT
November, 1958

A new concept in high temperature materials is represented in the introduction by Corning Glass Works of extremely thin-walled ceramics. Formed into light weight structures of alternate flat and corrugated sheets, the materials are suitable for continuous exposure to temperatures up to about 1300° F. Besides being resistant to oxidation and corrosion in the range of operating temperatures, a very low coefficient of thermal expansion is characteristic. This is in the order of 1×10^{-7} per °C in the range of temperatures up to 300° C. The ability to withstand extreme thermal shock is another characteristic. Capable of being formed in a wide range of shapes, possible use is indicated in gaseous heat exchangers, catalyst supports, burner plates, and structural applications in high temperature environments. Several ceramics have been successfully produced in the new form. Typical properties are: density—30 lb/ft^3; surface area—1500 ft^2/ft^3; specific—0.2 BTU/lb—° F; wall thickness— 0.005 in.

—from MECHANICAL ENGINEERING
November, 1958

COMMANDER S. R. HELLER, JR., USN

ON THE ADEQUACY OF THE LONGITUDINAL STRENGTH CALCULATION

THE AUTHOR

an Engineering Duty Officer of the United States Navy, was graduated from the University of Michigan with degrees in Naval Architecture and Marine Engineering and in Mathematics. Following graduation he was employed by the New York Shipbuilding Corporation. On entry into the U.S. Navy he was ordered to the Norfolk Naval Shipyard and assigned to carrier construction. After World War II he was ordered to the Massachusetts Institute of Technology for postgraduate instruction leading to the degrees of Naval Engineer and Doctor of Science in Naval Architecture. Since that time he has been Assistant for Aircraft Carriers in the Hull Design Branch of the Bureau of Ships, Maintenance Officer on the Staff of Commander Amphibious Group ONE, and is now Structural Mechanics Officer at David Taylor Model Basin.

INTRODUCTION

A FEW years ago this same JOURNAL published a paper (1)* by the same author in which he raised several questions about the wave geometry to be used in studying the longitudinal strength of ships. Specifically he pointed out several inconsistencies in the calculation as presently standardized and proposed, in some instances, means of rectifying these inconsistencies; but, inevitably, resigned himself to the sad conclusion that the standard calculation had achieved immortality.

In this paper the same general subject is discussed, but the emphasis is on the calculation of stress rather than bending moment. The thoughtful reader may rise in righteous indignation and ask: Why another paper on the tired topic of longitudinal strength? There is no simple answer; there are only hints.

The technical literature for the past century is replete with evasions and equivocal statements both on strength analysis and structural design of ships. The consensus is that the standard method of determining a ship's strength is on the basis of past performance. The *method of comparison* has become traditional. Periodically some young Lochinvar will come out of the west to do battle with tradition. The typical complaint against the method of determining a ship's strength has probably best been stated by Bengston (2): "In common with all methods that look exclusively to the past for guidance, it has shown itself incapable of substantial progress. Whatever advance has been made in the last quarter of a century is not so much by extension of our knowledge of a vessel's elastic behavior, or of the loads and forces which it must sustain, but largely by improvement of workmanship and materials used in construction." All too often the young Lochinvar finds himself transmuted into Don Quixote.

The author is naive enough to believe that the naval architects charged with the responsibility of designing the structure of ships want a method of analysis which will predict *actual* stress, so that design procedures can be based thereon. Unfortunately he is not yet prepared to offer that panacea. If, however, past history is studied together with recent developments, the route toward progress may be charted.

*Numbers in parentheses refer to the BIBLIOGRAPHY at the end of this paper.

USE OF SIMPLE-BEAM EQUATION

Just when the well-known simple-beam equation:

$$\sigma = \frac{Mc}{I} \quad \text{.....[1]}$$

where σ = stress
M = bending moment
c = distance from neutral axis to extreme fiber
I = moment of inertia about neutral axis

was first applied to the study of the longitudinal strength of ships is not documented. In the very first issue (1860) of the *Transactions of the Institution of Naval Architects,* the oldest technical society dealing with the shipbuilding profession, there did appear several papers dealing with "the strength of iron ships." In one of these, Fairbairn (3) proposed the consideration of the ship as a beam. Presumably this was based on his early work with iron bridges. His proposed equation was:

$$\triangle = \frac{adC'}{L} \quad \text{.....[2]}$$

where $\triangle$ = weight of ship in tons
a = area of deck (or keel) in square inches
d = effective depth in feet
C′ = constant (taken as 60)
L = length of ship in feet

At first glance there is little connection between Equations [1] and [2]. If, however, bending moment, M, is considered to be a fraction of the product of ship weight and length, $\triangle$ L/C (in which, as will be shown later, C usually has a value between 30 and 35), then the resemblance is startling.

Equation [1]		Equation [2]
$\frac{I}{c}$	$\approx$	ad
$\frac{M}{2}$	$\approx$	$\triangle$ L/C′

Then, Equation [2] can be rewritten approximately as:

$$\frac{Mc}{I} \approx 2 \quad \text{.....[2a]}$$

which is tantamount to a stress of two tons per square inch.

During the century that has elapsed, the simple-beam equation has continued in use, probably because of its extreme simplicity. Simplicity has many virtues, but adequacy is not necessarily one. Each of the quantities used in the simple-beam equation will be examined with a view toward adequacy—both individually and collectively.

Bending Moment

The chief controversy over the determination of the bending moment has been the wave geometry to be used. This feature has been amply discussed in (1), and the presently accepted procedure has been described. There has been, however, much discussion over the weight and its distribution to be used for the usual hogging and sagging calculations. The early investigators almost unanimously agreed that the full-load condition should be used. It remained for Champness (4) to prove rather conclusively that maximum hogging moments would be obtained with the ship loaded at the ends and light amidships, and, conversely, that maximum sagging moments exist when the ship is loaded amidships and light at the ends. Although the load conditions for maximum moment were clearly indicated, the actual determination of the most severe condition involved considerable labor. Naturally, since the conventional calculation produced only "comparative numbers," the determination of the most severe condition was not deemed worth the added complication. Ferris (5) produced an uncomplicated procedure for going from one condition to another rather quickly, so that the labor of determining the maximum moment is considerably lessened. With this tool in hand the U.S. Navy calculated, as a matter of routine, the maximum hogging and sagging moments, termed respectively "special hog" and "special sag," as well as the corresponding moments for the full-load condition. It also became standard practice to furnish operators of ships which, in service, could and did operate in a wide variety of load conditions (e.g., tankers) means for predicting the changes in stress arising from changes in load.

This method for determining maximum moment is fine for a ship that is already designed or in service. At the outset of design, when there is little known except the principal dimensions, what method should be used? Certainly it would be fortunate if the maximum (or design) moment could be approximated from quantities known at this early stage of design. If such an approximation could be made, then a similar approximation of the structural design and hence structural weight could also be made—and the process of design could go forward. Such an attempt was first made by John (6) who postulated:

$$M = \frac{\triangle L}{C} \quad \text{.....[3]}$$

and then, using data published by Reed (7), evaluated C for hogging at 35. Later investigations, notably (4), confirmed the general applicability of 35 for the hogging condition and 27 to 30 for sagging. In spite of the smaller C for sagging, the moment is smaller because of the smaller displacement used. Thus, for the first approximation of structural design, the bending moment widely used is:

$$M = \frac{\triangle L}{35} \quad \text{.....[3a]}$$

The accumulation of 40 years' experience in the

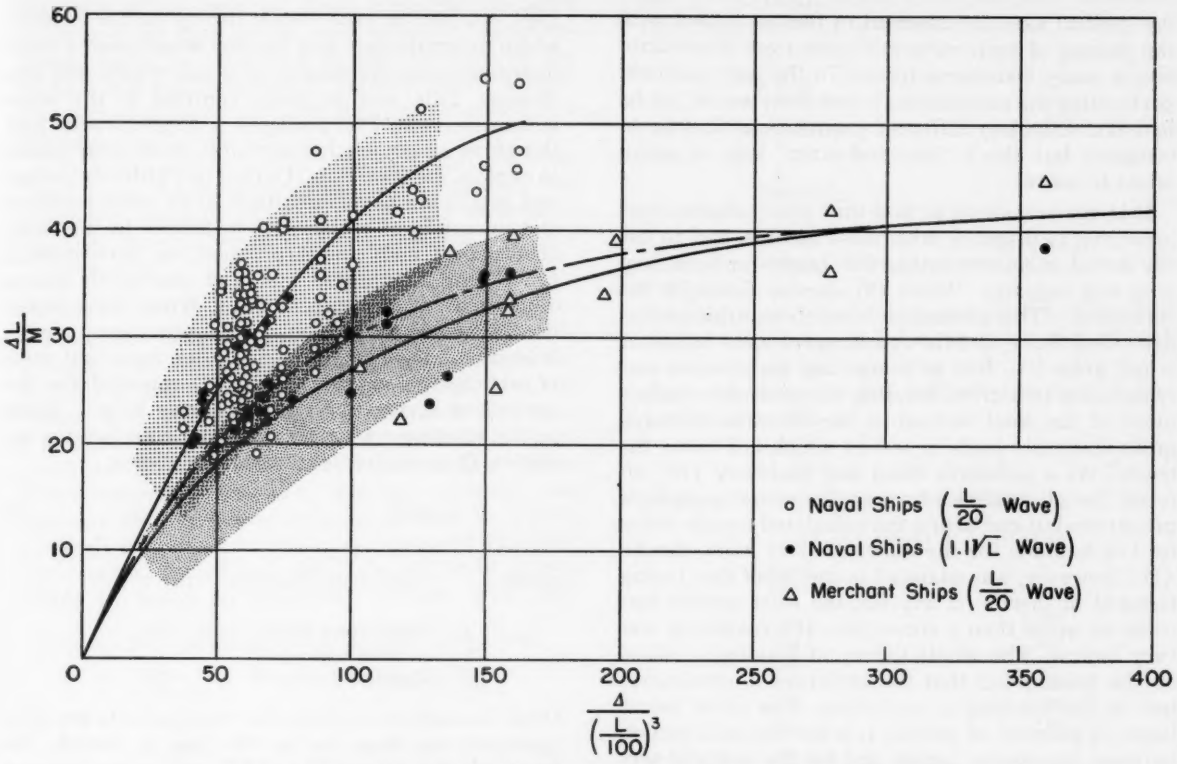

Figure 1. Approximation of Standard Bending Moment from Principal Dimensions.

U.S. Navy is presented in Figure 1. This clearly shows that the "bending moment constant," C, is far from constant. It will be noted that the "mean line" for naval ships (combatants) is very different from the corresponding "mean line" for merchant ships (noncombatants) if the L/20 wave* is used. This, of course, reflects the differences in weight and buoyancy distribution.

The U.S. Navy has now taken the $1.1\sqrt{L}$ wave** as its standard. Although the data for the new standard are somewhat scanty, the "dot-dash" line has been shown in Figure 1 as a tentative "mean line." In the transition period before final acceptance of the $1.1\sqrt{L}$ wave, bending moments were calculated for both waves. In every case the difference in moment is directly attributable to the difference in wave height. This is explained by the inequality of height:

$$1.1\sqrt{L} \geq L/20 \quad L \leq 484 \qquad \text{.....[4]}$$

That is, for wave length (and therefore ship length) less than 484 feet, the wave height (and hence bending moment) for the $1.1\sqrt{L}$ wave is greater than for the L/20 wave; the converse is true for lengths greater than 484 feet.

In any event the relations shown in Figure 1 are suitable for the first estimate of bending moment, and thereby the structural design of a ship, provided the somewhat artificial conditions assumed in the standard calculation are acceptable.

Moment of Inertia and Section Modulus.

At first glance it would appear that these two interrelated items would pose no problem, and that they would be determined simply by normal geometric processes. Early analysts, however, reasoned otherwise. It was their thought that the line of rivets whereby structural profiles were joined to plating constituted a weakness. For this reason John (8) proposed to consider the area subjected to tension reduced by 1/7 to allow for rivet holes.* John also suggested that only the "effective width"** of plating in compression be considered. To many practical shipbuilders this was an anomalous procedure for

*Wave height, H, from crest to trough is L/20.
**Wave height, H, from crest to trough is $1.1\sqrt{L}$.

*It was considered that, since rivets were driven hot and shrank on cooling, they did not fill the holes when the plate was in tension.
**That portion of plating which, even after buckling, could still be considered to act with the attached stiffener.

the neutral axis and moment of inertia shifted with the passing of each wave and were even discontinuous at every transverse frame. To the poor engineer performing the calculations it was even worse; for he had not only two different moments of inertia to compute, but also a "trial-and-error" type of calculation to make.

It is not surprising to find that many shipbuilders preferred to dispense with these niceties and to use the actual geometric properties (same for both hogging and sagging). White (9) decries this with the statement: "This procedure is not so accurate as that described above, and the resulting economy in labour is not great . . . But in computing the stresses corresponding to a given bending moment, the employment of the total instead of the effective sectional areas obviously leads to results which fall below the truth." As a palliative Read and Stanbury (10) offered the alternative of using the actual geometric properties but increasing the calculated tensile stress by 1/6 to allow for the effect of rivet holes. Bruhn (11), however, was adamant in the belief that basing moment of inertia on any but the *solid section* was more an error than a correction. His reasoning was very logical: The whole theory of bending is based on the assumption that the structure is continuous just as the bending is continuous. The usual calculation of moment of inertia, I, is for the solid section between transverse frames and for the reduced section at frames which assumes that the structure (I and location of neutral axis) is discontinuous. These two assumptions are incompatible.

As might have been suspected, logic did not immediately overcome tradition. In 1905 the British Admiralty conducted full-scale tests on the destroyer *Wolf*, the results of which were reported by Biles (12). Biles computed I in the traditional way—deducting for rivet holes in the tension flange. When he could not find agreement between his observed and calculated deflections,* he followed the concept that the effective modulus of elasticity of the structure was substantially less than the modulus of the basic material (10). The field was now open wide, and practically all authorities poured through, advancing various theories to explain the *Wolf* data.

Pietzker (13) proposed *his* theory of "effective width"—40 thicknesses of plating acting in consort with longitudinals. Whereas Pietzker proposed an effective width on both the tension and compression sides, Hovgaard (14) modified the effective width to 60 thicknesses on the compression side and used the intact area on the tension side. Hoffman (15) proposed the modification of Pietzker's method to give some credit to plating outside the effective width on the basis that, although buckled, it could still contribute to the stiffness of the hull girder. Schnadel (16) applied modern elastic theory to the effective width determination and thereby determined a stress distribution on the compressive side which was *continuous*. This was in sharp contrast to the other authorities who had proposed a discontinuous and, therefore, an obviously impossible stress distribution to explain the *Wolf* data. During this hubbub student and practicing naval architects alike were confused and uncertain of which path to follow. In the midst of proposal and counterproposal an International Load Line Committee met and discussed, among other matters, strength of ships. When their report was subsequently ratified as an international treaty, it became a legal requirement on the merchant ships of participating nations. Abell (17) reported that the prescribed section modulus, I/c, was largely based on the *existing requirements* of the classification societies. This requirement exists in the form:

$$\frac{I}{c} = fBH \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [5]$$

where $\frac{I}{c}$ = section modulus in in.^{2}-ft.

f = factor from Table I in in.^{2}/ft.
B = molded beam in ft.
H = summer draft in ft.

Other limitations are that the requirements are only applicable to ships up to 600 feet in length, for length/depth ratio of 10 to 13.5, and beams that are a tenth of length plus 5 to 20 feet. Ships that fall outside these limitations must be judged by the classification societies on their own merits. The values of f given in (17) were slightly reduced in a later International Load Line Treaty (ratified by the United States in 1930). The latter are required of the U.S. merchant ships in accordance with (18). It is interesting to note that the Load Line Treaties authorize the calculation of I for the *solid section*.

TABLE I—*Section Modulus Factors*

Length (ft)	f(17) (in.^{2}/ft)	f(18) (in.^{2}/ft)
100	2	1.8
200	4	3.6
300	7.7	6.95
400	12.5	11.2
500	18	16.25
600	24.6	22

Shortly before World War II the U.S. Navy permitted publication of data collected in 1931 from full-scale tests on two destroyers, *Preston* and *Bruce*. In a memorable paper (19), Kell reported the most intensive and best instrumented full-scale structural investigation of ships up to that time. From these carefully conducted experiments came the conclusion that the moment of inertia should be calculated for the *solid section* comprising all longitudinally continous material with no deduction for rivet holes. It was further concluded that the modulus of elasticity of the structure was the *same* as the modulus of

*Biles neglected the effect of shear on deflections although this had been shown to be appreciable by Read and Stanbury (10) a decade earlier.

elasticity of the material. That these findings were confirmed by both strain and deflection measurements made no difference to the devotees of the various theories proposed to explain the *Wolf* tests. The feet of clay of their idols had been exposed, and they were dumbfounded.

The wheel had turned full circle in eight decades. Once more the naval architect could calculate the geometric moment of inertia, use the laboratory value of the modulus of elasticity, and feel confident in his results.

Stress.

From the designer's point of view it is desirable to assume an allowable stress and, from it, proportion the ship girder to suit the bending moment. It would follow that, once the material had been chosen, a fraction of its yield (or ultimate) strength would be permitted. This, of course, was too simple and logical. Notwithstanding the fact that the material can scarcely know whether it is being used in a large or small ship, early investigators proposed allowable stresses that varied with size. John (6) gave figures, Table II, based on registered tonnage. Still later

TABLE II—*Proposed Allowable Stresses (John, 1874)*

Registered Tonnage	Allowable Stress (Tons/sq. in.)
100	1.67
200	2.36
300	3.09
400	3.55
500	3.95
600	3.72
700	4.57
800	4.59
900	4.8
1000	5.19
1500	5.34
2000	5.9
2500	7.08
3000	8.09

through a rather involved quasi-dimensional analysis Abell (17) suggested:

$$\sigma_{all} = 5 + \frac{L}{200} \quad \ldots\ldots [6]$$

To Abell's credit it must be stated that he realized that wave height was not in constant ratio to wave length, and this was his way of removing the penalty of the standard bending-moment calculation from the long ship. At about this same time many naval architects in Great Britain were carrying on a running feud with the classification societies to allow somewhat higher stresses in fuller ships. They pointed to results shown by Champness (4) and reasoned along these lines: *

If Equations [1], [3], and [5] are combined, the result is:

$$\sigma_{all} = \frac{\Delta L}{35fBH} \quad \ldots\ldots [7]$$

*A more detailed account is given by Barnaby (20).

But $\Delta = C_b LBH$, where C_b is the block coefficient. Thus, Equation [7] becomes:

$$\sigma_{all} = \frac{C_b L^2}{1225f} \quad \ldots\ldots [7a]$$

For the very full ship ($C_b = 0.8$), Equation [7a] becomes:

$$\sigma_{all} = \frac{0.000653L^2}{f} \quad \ldots\ldots [7b]$$

which, for values of f (18) from Table I, is plotted in Figure 2.

A slightly different form mentioned by Champness (4), but attributed to Tobin, proposes that allowable stress vary as the cube root of length. Arnott (21) gives a version of this relation based on a block coefficient of 0.75 as:

$$\sigma_{all} = k \sqrt[3]{L} \quad \ldots\ldots [8]$$

where k has values given in Table III.

TABLE III—*Values of k (Arnott)*

Length (ft)	k
100	0.733
200	1.164
300	1.185
400	1.189
500	1.189
600	1.189

All these proposals for allowable stresses show variation with size, principally length. These schemes have no real foundation insofar as the properties of materials are concerned for they make no distinction between materials (i.e., they are based on medium steel) and they belie the fact that the materials are unaware of their use. It appears that their chief virtues are that they partially remove the penalty for a somewhat unrealistic standard calculation, and they are conservative. Equations [6], [7b], and [8] are plotted in Figure 2 together with values calculated for practically all naval ships designed since World War I and the very large transatlantic passenger liners. It will be noted that there are only a few naval ships for which calculated stresses exceed the uppermost curve, and there is no history of structural distress in them. Nor is there any documentary evidence of how much excess material there is.

Recently St. Denis (22) proposed a scheme of taking into account not only the ship girder stress (with which the foregoing has dealt exclusively), but also the effect of local loads on both longitudinal girders and plating. In addition, he proposed to consider the strength of the material used. Certainly this is a more logical design process than any heretofore suggested.

SUMMARY

The present state of the art is to infer a design bending moment from balancing a ship statically on a "standard" wave of arbitrary profile and propor-

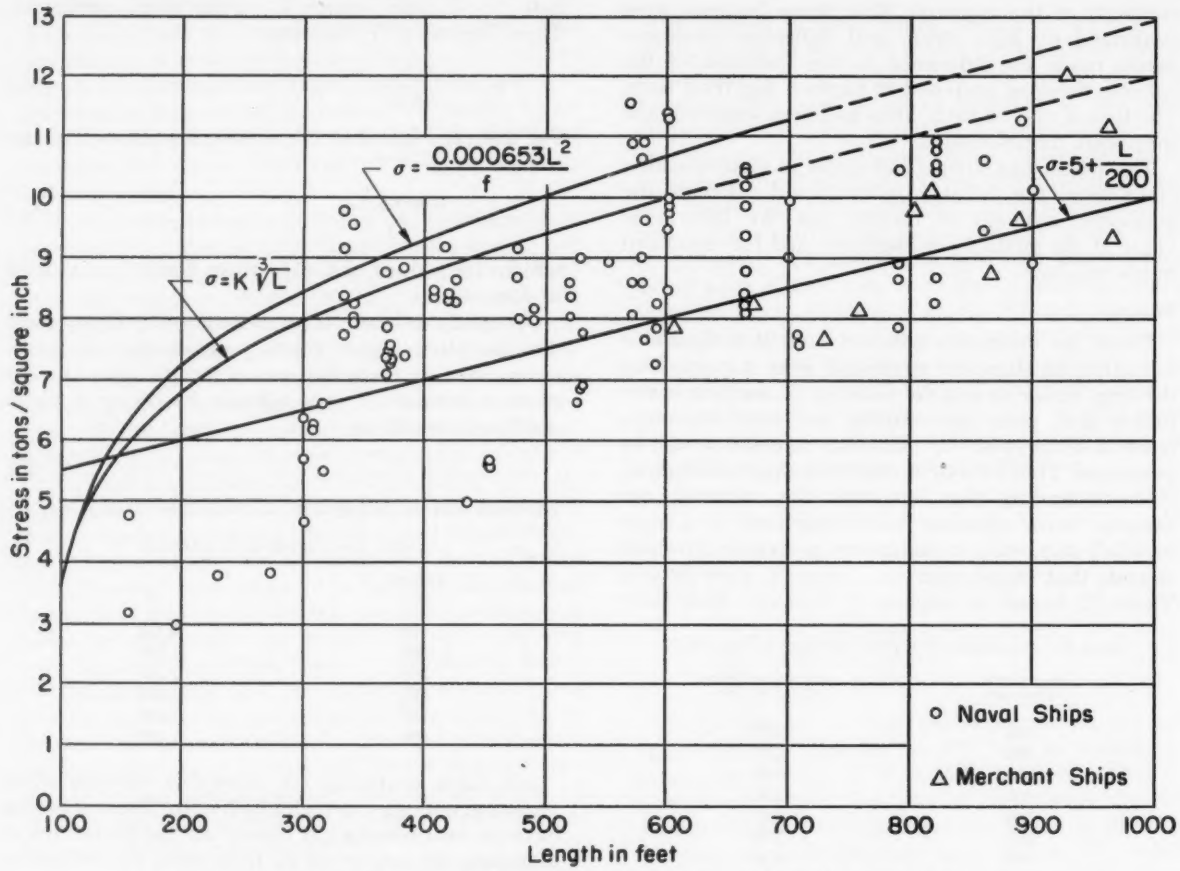

Figure 2. Comparison of Allowable Stresses with Values Computed from Standard Calculations.

tions; to limit the stress according to another equally arbitrary rule that somehow accounts for the unreality of the bending-moment calculation; and, finally, to proportion the structure to give the section modulus, calculated for the intact area, which, together with the other quantities, satisfies Equation [1]. That this procedure works—and on the whole it works rather well—is a tribute to the judgment of the men who apply it. The successful design of a structure when the loads to which it is subjected are unknown is a truly phenomenal performance.

If, however, the forces and the resulting bending moments are known (and this is the case for the carefully conducted static experiments on ships), the stresses calculated from observed strains are in good agreement with stresses predicted by beam theory as is pointed out by Evans (23). It appears then that Equation [1] is a useful tool for the analysis of data when section modulus and stress (in the usual case, strain) are known. To design for dynamic loads on the basis of an arbitrary static load is a somewhat doubtful procedure.

Recent tests at sea, such as those conducted by Jasper and Birmingham (24), give rise to the hope that dynamic bending moments can be correlated even as the static ones are now, see Figure 1. Many more tests will be required, but a start has been made. It also seems possible that model tests in irregular seas together with the scaling laws alluded to in (24) may give load information in advance of actual design as a matter of routine just as is now done for resistance and propulsion data. The Maneuvering Basin now under construction at the David Taylor Model Basin is anticipated to be a facility capable of doing this work.

CONCLUSIONS

The results of this study are simply:

1. If courses or moments are known and section moduli are calculated for the intact areas, the simple-beam theory predicts stresses adequately.

2. Conversely, if stresses are derived from observed strain measurements and intact area section moduli are used, the simple-beam theory adequately predicts bending moments.

3. For design purposes, the artificial static bending moment together with arbitrary allowable stresses and beam theory will produce a design that is fairly

safe, but will not permit refinements of structural design.

4. Better knowledge of dynamic loads and bending moments is required for progress in structural design.

5. Model tests with sufficient full-scale tests for confirmation appear desirable.

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New demands for increased maneuverability of ships have been evolving in recent years, because of increases in the density of sea traffic in port areas, and because of the high cost and inconvenience of tug assistance. Several devices have been used to increase control of the stern, but until recently no promising solution of obtaining adequate bow maneuverability had been developed. Among the recent promising approaches are the axial blade type propeller, projecting from the keel in the vicinity of the bow, or mounted in an athwartship tunnel near the bow. Another solution is the new installation in the Rhine freighter "Compiegne" of two athwartships bow tunnels, each containing a submerged electric motor of the type used in active rudder installations driving a conventional propeller. A thrust of about 80,000 pounds using two 125 HP motors is expected when the ship has no way on.

—from SHIPPING WORLD
August 29, 1958

The simulation of loads on structural members, caused by nuclear explosions, with the use of conventional explosives is of considerable importance for simple and economical test procedures. A 20-ton steel pressure vessel has been designed to allow such tests, and placed in service at the Naval Civil Engineering Laboratory at Port Hueneme, Calif. Roughly cylindrical in shape, the vessel is mounted on top of a heavily reinforced concrete pier. The test specimen is mounted inside and suitable quantities of primer cord provide the desired explosive loading. Pressures of from 20 to 185 psi can be reached in 1 to 2.3 milliseconds, the amplitude and time-to-peak-pressure being controlled to simulate the characteristics of an atomic explosion.

—A.S.M.E. Press Release
December, 1958

A spherical, inflatable fabric surface, imbedded with spirally wound conducting strips shows considerable promise as a radar antenna. Its principle characteristic is its property of behaving like a lens to focus radar waves into an intense narrow beam—a function generally requiring a large rotatable antenna. Under development by the Westinghouse Electric Corporation, and called the "Helisphere", this antenna is not required to rotate. Instead a small feeder horn in its interior, rotating and aimed horizontally at the inside surface, sprays radar waves on the inner surface. The polarization phenomenon causes the surface to act as a focusing reflector, projecting the waves through the opposite side of the sphere as a narrow beam. The sphere is held in shape by low air pressure —about one-tenth pounds per square inch. In stationary installations, the Helisphere can be enclosed within another inflatable structure or radome to protect it from the wind and elements. Preliminary experiments have indicated the possibility of a one-degree beam with good elevation coverage and no undue problems with spurious radiations in off-beam directions.

—from WESTINGHOUSE ENGINEER
November, 1958

An unusual generator installation is planned for two British Diesel-propelled tankers, in which the generators will be built as an integral part of the propeller shafts and thus require no separate prime mover. Advantages claimed for this type of installation are:

(1) A reduction in the use of auxiliary generating equipment, resulting in lower running costs, less maintenance and fewer spares.
(2) Increased efficiency.
(3) Simplified watch duties.
(4) Utilization of marginal space for additional power.

The main requirements given in the specifications include a prohibition against welding on the main shaft, a constant voltage output over the shaft speed range from 80 to 126 rpm, and a provision that the lower half of the unit be watertight. Recognized problems in such an installation derive from shaft speed irregularity, shaft currents, maintenance problems, and movement of the ship's structure relative to the shaft.

—from THE SHIPBUILDER AND MARINE ENGINE-BUILDER
November, 1958

GUILLERMO ESCALANTE

DYNAMICAL STABILITY ON BOARD

THE AUTHOR

graduated in Civil Engineering from University of the Litoral (Argentine) in 1944, and in Naval Architecture and Marine Engineering from University of Buenos Aires in 1946.

He has served in the Argentine Navy, in the Naval Constructors Corps for eleven years. In 1949 he was doing a training period in submarine repairs at Philadelphia Navy Yard, and another one in ship construction at New York Shipbuilding Corp., Camden, N.J.

Now he is Director of Boiler Factory "Sociedad Caren," Assistant Professor of Marine Engineering I in University of Buenos Aires and associate in a private technical office in naval architecture and marine engineering at Buenos Aires.

In the Damage Control Course, in both our Training Centers and similar foreign Naval Schools, study of stability has a dual purpose.

First to train Stability Officers, who must be valuable Chief Assistants, and second to indoctrinate Commanding Officers with a general knowledge of the subject which will permit them to appreciate stability situations analyzed by the Damage Control Organization as an aid to operational decisions.

Subjects treated in this chapter have the following objectives, and after a brief review of the fundamentals of buoyancy and stability, the student officers are taught:

(a) TO KNOW HOW to draw as quickly as possible the curve of stability of the ship at any time, damaged or not,

(b) TO KNOW HOW to analyze that curve.

(c) TO KNOW HOW to fix their minds concerning the ability of the ship to resist sea forces, taking account of (b).

Item (a) is developed without trouble, teaching simplified, practical and fast methods with no more precision than necessary.

In item (b) are pointed out five fundamental characteristics of the stability curve:

(1) Metacentric height

(2) Maximum righting arm.

(3) Angle of heel corresponding to maximum righting arm

(4) Range

(5) Dynamical stability

In item (c) the first four characteristics are judged qualitatively and quantitatively establishing some criteria for estimation of the stability situation.

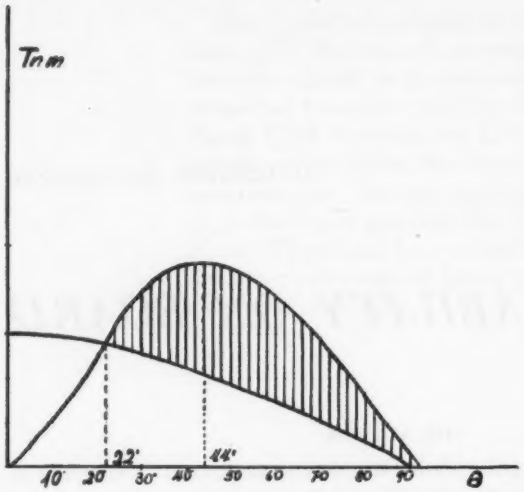
About characteristic number 5, dynamic stability, little or nothing is said. So considering some textbooks which are used in Training Centers in the United States we can read:

(1) HANDBOOK OF DAMAGE CONTROL. Chapter IV.—Stability characteristics.

". . . However it is more useful not to obtain dynamical stability as a numerical figure but rather to compare the areas under two curves for the ship in different conditions. Such a comparison provides a means, for example, of observing the relative resistance to capsizing before and after damage in terms of the work required to overturn the ship. Total dynamic stability is therefore one index to the safety of the ship."

In Chapter XIII. Impaired stability.—Only a reference is made:

". . . Compare the areas of curve before and after flooding" without any quantitative indication that could be adopted as an approximate criterion.



Handbook of Damage Control
Fig. 17-1

In Chapter XVII. Estimate of the damaged ship's situation.

". . . In order to visualize the dynamic stability still remaining after off center flooding has caused the ship to list, refer to figure 17-1. In this figure we have a static stability curve for the intact ship, the angle of maximum righting arm being 44°. Superimposed on this, is the inclining moment curve due to moving a weight off center. In this example the angle of permanent list 22°, is equal to one half of the angle at which the maximum righting arm occurs on the intact stability curve. The shaded area represents the residual dynamic stability. It should be noted that this residual dynamic stability is much less than half the original total dynamic stability. In addition, if the list had been due to off center flooding, the combined effects of added weight, free surface and free communication would normally have resulted in a smaller stability curve than the original intact one. The residual dynamic stability due to flooding therefore would be even less than that resulting from moving a weight off center to produce an equal permanent list."

(2) DAMAGE CONTROL by Thomas J. Kelly.—Chapter XVIII.—Buoyancy and stability in damaged conditions.

". . . But the most serious effect of reduction of metacentric height is the reduction of dynamic stability. . ."

". . . but the dynamic stability of the damaged ship offers much less resistance to the dynamic impulses of the sea and the wind and therefore materially reduced chances of survival in the open sea . . ."

". . . Dynamical effects materially reduce the magnitude of the static couple which a ship can withstand and particularly in the case of serious underwater damage may be determinative in the loss or survival of the ship."

(3) PRINCIPLES OF WARSHIP CONSTRUCTION AND DAMAGE CONTROL, by G. C. Manning and T. L. Schumacher.—Chapter VIII.—Hull Damage.

". . . We thus see that a sea which invloves no danger at all for the undamaged ship will, when she is damaged as assumed, not only endanger her but will certainly cause her to be lost. The vessel may still be stable and buoyant after damage but entirely unseaworthy due to the reduction in dynamic stability through modification of her static stability curve; and this effect may be produced in connection with the complete flooding of compartments even though such flooding has increased the vessel's initial stability."

Although dynamic stability is a measure of exceptional value for estimating the operational aptitude of the ship, because it represents the heeling energy (sea and wind) which the ship is capable of absorbing without capsizing, it can not be found mentioned in textbooks what dynamic stability criterion is to be used; which of the characteristics of the stability curve can best be used in a quantitative way so that the Commanding Officer can guess what will be the ship's situation in a seaway.

The purpose of this paper is to show a new method that the author has not found in textbooks, pointing out that the idea about the subject was first given to him by Lieut. Commander Siffredi, Argentine Navy.

The method consists in drawing polar diagrams for a particular ship (one for each speed, for example 5, 10, 15, 20 and 25 knots) whose angular coordinate is the angle between ship course and direction of the sea. In other words:

sea by the stem 0°
sea by the stern 180°
sea by the port side 270°
sea by the starboard side 90°

and the radial coordinate is the dynamic stability measured in area units of the curve of righting moments (Fig. 1).

In these polar diagrams observations can be plotted and finally different curves can be outlined.

Take, for example, the diagram corresponding to 15 knots.

On observation day the ship has a particular stability curve as is indicated in Fig. 2. Ship is steaming in sea number 3 with an angular coordinate 135° (sea on starboard quarter).

Observing average maximum rolling angles or, better than that, registering rolls on a rollgraph as indicated in Fig. 3, a determined maximum angle of roll representative of this situation, say 7 degrees,

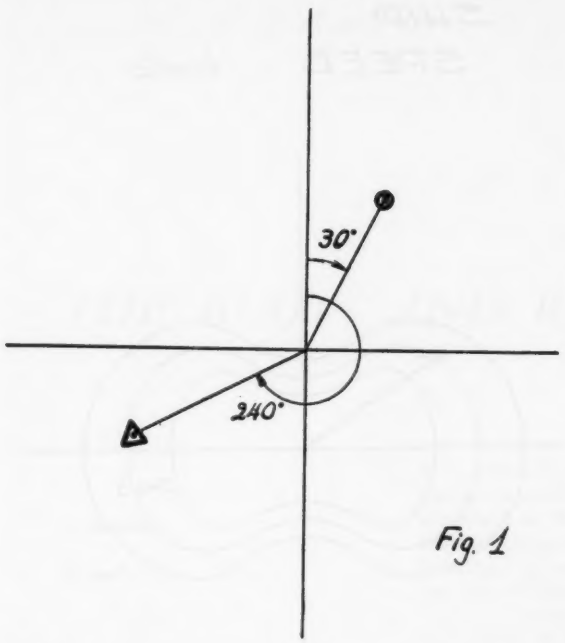


Fig. 1

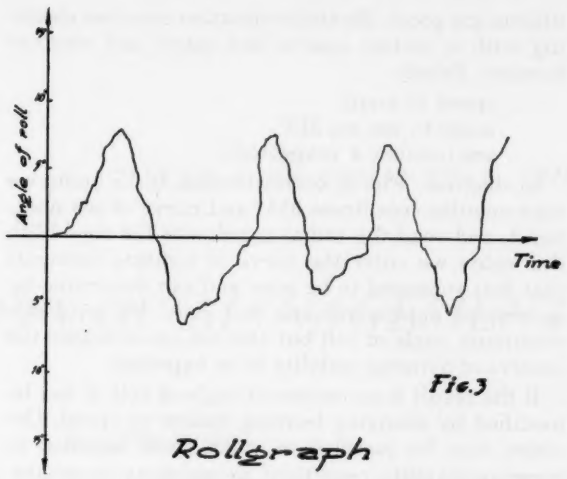


Fig.3

Rollgraph

can be selected. Taking this value on the curve of righting moments (Fig. 2) we obtain Fig. 4 where the shaded area represents, on a certain scale, dynamic stability wasted against wind and sea, but in the present study we need only relative values. Then we can use any scale, provided always that the same one is used. In this manner we plot a point in accordance with references indicated in Fig. 5.

Following the same procedure with different sea number (height of wave) and different angles to the sea we obtain a number of plots individualized with reference to Fig. 5 and then we outline the final diagram for 15 knots. We can estimate what the shape of curves will be as indicated. The rest of the diagrams, one for each speed, will be laid out in the same way.

USE OF DIAGRAMS.—The diagrams are used with a reverse procedure in the following manner:

We suppose that Command wants to estimate the situation with these data: stability conditions (ship damaged or not) are not sufficiently good (nobody knows how much, but everybody knows that con-

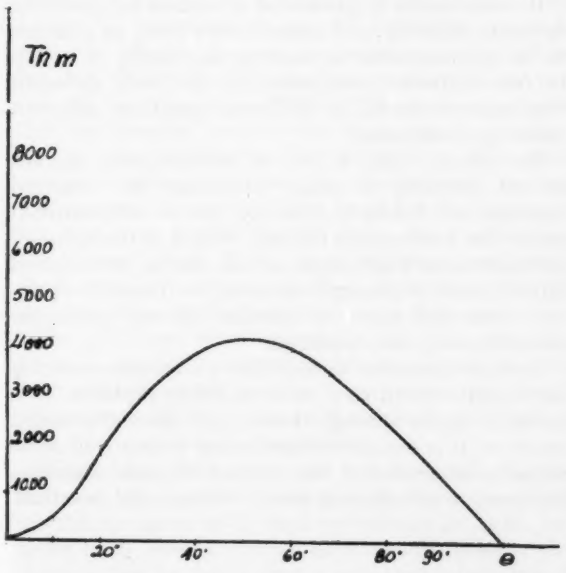


Fig 2

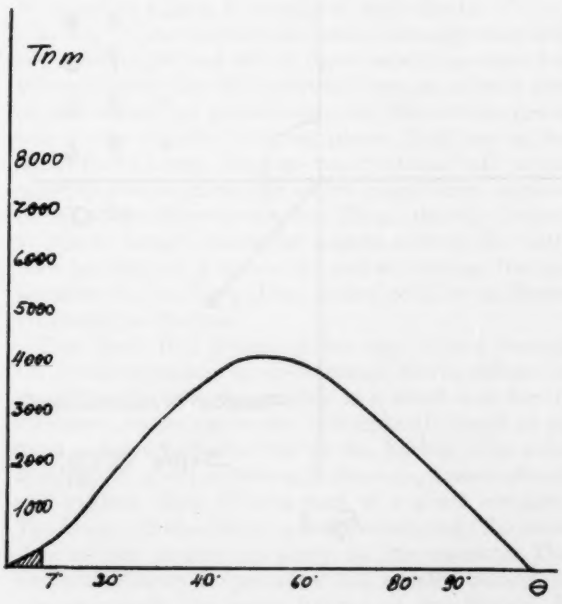


Fig 4

ditions are poor). Strategic situation requires steaming with a certain course and speed and weather forecast. Briefly

speed 15 knots
angle to the sea 315°
sea number 4 (expected)

In diagram, Fig. 6, corresponding to 15 knots we take angular coordinate 315° and curve of sea number 4, and read the radial coordinate 120 cm.² With this value we enter the curve of righting moments that was supposed to be poor and can determine by successive approximations, not only the probable maximum angle of roll but also we can visualize the reserve of dynamic stability to be expected.

If the result is an excessive angle of roll, it can be modified by changing bearing, course or speed. Decision may be justified to make some sacrifice to improve stability conditions as much as necessary. A new and quick study gives a convenient determination of maximum angle of roll that will give an acceptable margin of safety, taking account of the general situation.

Thus, is outlined a method that is proposed but

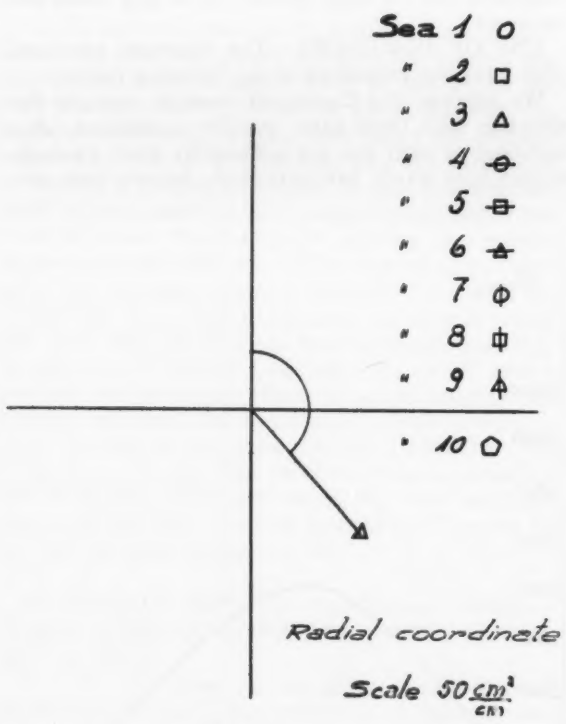


Fig 5

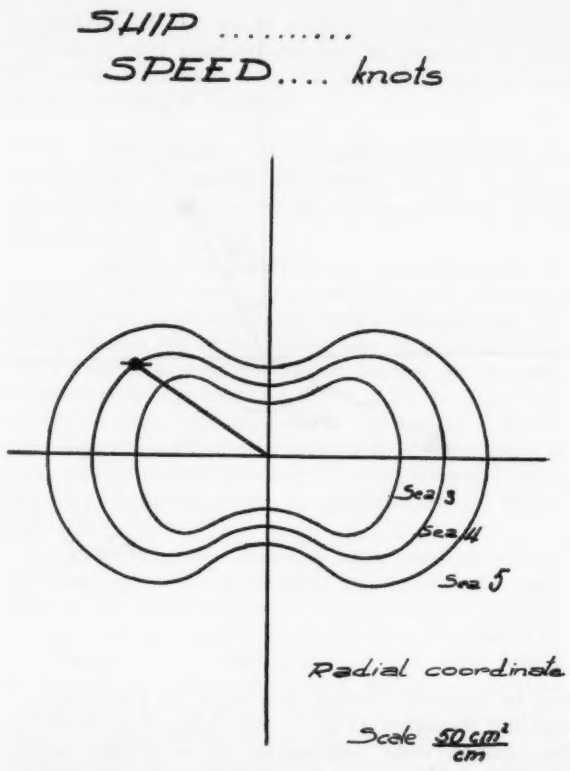


Fig. 6

which must be experienced to make a final assertion about its excellence.

CONCLUSION

In these notes is presented a method for utilizing dynamic stability in a quantitative form as a factor to be considered for estimating the ability of a ship to face different conditions of sea with different bearing courses and at different speeds in different stability conditions.

To obtain this, a lot of observations at sea permit plotting in polar diagrams the required measure of dynamic stability (in a conventional scale) for confronting the sea. With this the value of probable maximum angle of roll can be determined quickly, and the margin of safety in dynamic stability, using the curve of stability in any particular condition may be visualized.

It is not intended to establish a supreme criterion for decision even in a pure stability problem. It is simply a factor among others to influence Command decision. It is considered necessary to test it in some ships to determine if the method of polar diagrams outlined on a statistical basis, is sound and practical.

CAPTAIN JOHN ADRIAN HACK, USN

THE BUOYS AND REEFS OF MANAGEMENT

THE AUTHOR

is a graduate of the U.S. Naval Academy in the Class of 1935. After varied service in battleships, destroyers and submarines he received a postgraduate education in Management Engineering at Rensselaer Polytechnic Institute in 1949-50. Since then he has been able to observe and to introduce many of the principles of management into the Fleet administration. The author of numerous articles, he has served on ships of the Destroyer and Amphibious Forces in recent years, and in 1957 graduated from the Naval War College. At present he is the Director of the U.S. Navy Management School, a component part of the U.S. Naval Postgraduate School at Monterey, California. This is the sixth article about Captain O'Shaughnessy published in the Journal, the last being "Captain O'Shaughnessy Learns a Lesson" in February 1957.

You remember Elizabeth O'Shaughnessy! You do, that is, if you have been in the Navy for very long, because she is the kind of girl you would not allow to pass by unnoticed. It may have been at a cocktail party in Manila years ago—perhaps it was on the beach at Coronado. You may have talked to her outside of the Chapel in Norfolk. It could have been that she stopped and chatted while you were shopping in the neighborhood grocery store. Wherever it was, whether she was in a housedress, visiting with you over a cup of coffee, or in her formal, dancing with you at the officers' club, you'd remember Liz! I don't think that you would even recall that she is a beautiful woman, with a slight streak of grey showing through that red hair—nor that she's vivacious and loves every minute of life. You wouldn't because she has one quality which overwhelms the memories of all others. She loves people, and you'd remember only that she paid so much attention to *you*. She made you feel important.

When Mike O'Shaughnessy was troubled, she was the one who patiently listened to him; was wise enough to agree with most everything he said; but being Irish, human enough to get mad whenever she thought that he was trying to make mountains out of molehills. Elizabeth had the theory that life could be most enjoyable, and most certainly was very simple and uncomplicated, if only one had the courage to keep it that way. The answer always could be found in a faith in people as individuals.

A day which Captain Michael O'Shaughnessy will not soon forget was one of those occasions when her temper flared. The kids were old enough to take care of themselves for a few hours. So Mike drove Liz to one of his favorite *thinking* places, high up on the tip of Point Loma. Here he could sit and talk, while his eyes swept across the entire magnificent scene—the skyline of downtown San Diego, the Air Station at North Island where the planes looked like little bees landing on a sidewalk, and out across the approaches to San Diego Bay, dotted with toy sailboats glistening in the sun.

The Navy had gotten so big that it was beyond his comprehension. As a dedicated Naval Officer he knew that he was responsible in a small way for its direction. Years ago it was so simple. He could sit up here and see half the fleet in the harbor. The solutions to the small problems of those days were almost self evident. Now he was part of a giant complex. The United States Navy was approximately the same size as the largest company in the country. The General Motors Corporation has a sales budget of approximately the same figures as the Navy's. If one counts the dealers throughout the country, both organizations have approximately a million persons

in their employ. Once he had only to be skilled in the art of warfare at sea. Now he had to be a master in the skill of directing a large complex organization of weapons systems, facilities, and materiels. He had a growing uneasiness that because of the explosive technical advances and the extreme diversification, the positions he would hold in the future would be too much for his brain to master. There were too many things to be coordinated. He couldn't even see all the problems, much less the solutions to them. He was being overwhelmed by the magnitude of the responsibilities he bore.

Elizabeth broke into his monologue. "Mike," she challenged, "I've seen you change and haven't liked it one little bit. I can remember the days when you'd come up here and tell me about the people on your ship. Your mind would be on Jimmy Jones, and the problems he was having with his family. You'd be so proud of the wonderful things the men about you were accomplishing. You always had such faith in every individual on your ship. But now your mind and your words are always on the things that you see. You worry about the material condition of the ships. You speak of the difficulties of managing the vast industrial activities of the Navy. You keep saying that we have to get more money to buy weapons with which we can defend our country. For goodness sake, Mike, have you forgotten that there is such a word as people? Life hasn't really changed. You haven't been able to understand that for you have been too engrossed with materialism. God created two individuals and placed them in the Garden of Eden. He gave them the same rights which we still remembered, and which they still had, when we wrote the Declaration of Independence. From that time, until the present, he has created nothing other than the individuals in the world. Those people haven't changed, and never will. He gives each one a heart, and a brain. Each has the same basic spirit and feelings. The things which you worry about are nothing more than the devices which they have made. When you can fully understand that, you won't have your misgivings about yourself, or your Navy."

"Do you see that ship leaving the harbor? There is a Captain on her bridge and he is her master. He could, if he chose, guide her around that point off North Island and head seaward. But he knows that if he does, his ship will ground on the reef. Someone who went before him probably did that, and marked the shoal. Others were more fortunate and wise. They marked a safe channel with buoys, so that all who followed, including that Captain, could avoid the reef and head safely for sea."

"Isn't it just as logical that you and your fellow naval officers should do that in running your Navy? Doesn't it make sense that the experiences which men have recorded, since they first lived in the caves, are nothing more than buoys and reefs for you to follow on the one hand, and avoid on the other? I don't know anything about your Navy, Captain O'Shaughnessy, but there is one thing I am very sure of! *People are people.* As individuals, each one is quite a guy. I've seen very few who weren't decent, intelligent, and responsible citizens, if only someone else had faith in them and allowed them to prove it! Sputniks, guided missiles, airplanes, shipyards aren't worthy of your worry. These things are nothing but machines which some individual has devised. Your worry should be that you don't pile up on the same reefs which have been marked out for you. Find the buoys other men have planted, and which will lead you to success. Your Navy is an organization composed of fine individuals who are as anxious as you are to defend our country. Give them guidance and faith. You'll be surprised how simple each problem will be, when some individual faces each one as though it is *his* problem! Study so that you find the buoys, Mike! Worry and talk about all these material things will get you nowhere!"

It may not be as simple as Elizabeth O'Shaughnessy made it out to be. Mike knew that. But he knew too that he had better not ignore her advice. He hadn't forgotten the lesson in household economics which had led to the preparation of a realistic Fleet budget.[1] Captain O'Shaughnessy spent months studying the experiences of men working together in nations, religions, and companies. He talked with anyone willing to teach him. You may not agree with his findings and his beliefs. But if you do not choose to follow these buoys, which he has outlined, you should be warned of the reefs which may lie behind them.

THE EVOLUTION OF AN ORGANIZATION

From the time when man first came out of his cave and found that there were other men with whom he might associate, the pattern of growth of organizations and the evolutions of problems which arise in human relations have a remarkable similarity. Man associates with man to increase his own individual well being—not to submerge himself in a system in which each becomes equal in unimportance. Being motivated also by the spiritual, there is the desire to help others so that all may enjoy a better way of life. Even in the first little group, one man had a bold and aggressive new idea. In competition with other ideas his was successful and flourished. He attracted followers. Success produced growth. The very devotion to a cause, the very intelligence which caused success, lured him toward centralization of power and direction. For there is an irresistible logic which urges a man to gather around himself the experts who know the details of the idea from its inception. Since each knows more about a particular facet of the idea than anyone else, specialized functionalism flourishes. Obviously these men can plan for continued success better than others, for they

[1]Captain O'Shaughnessy—Is Your Budget Bulging? THE JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS. May 1955.

have already proven in bitter competition that they have done so. They alone can see the broad picture, for they alone shared in the original vision. Just as logically, these men can best execute the plans they have devised. Finally followers become so numerous that *Bigness* comes, and with it complexities in communications and control. Ideas no longer can flow readily up and down the hierarchy of individuals making up the organization. Mistakes are made and now appear to be so costly that they cannot be allowed to happen again. Controls become more rigid. For the stakes are higher and the tumble into oblivion is from a pinnacle. The lure to continue toward the one best way to success becomes more brilliant and necessary to the men on top. It appears very logical that national survival, the existence of a corporation, or the saving of souls of all future generations demand even more centralized administration. Functionalization finally concentrates attention so completely on *things*, that it becomes difficult for the leader to realize that just as people are responsible for all achievements, so are they responsible for all problems. Bigness, lack of communications from the individuals to the leader, concentration at the top on material requirement necessary to maintain success, finally breeds unbalance. The methods which brought success become incompatible with further success, or even survival. For throughout the organization are men who associated with the group in order to increase their own individual well being, not to be submerged and become unimportant cogs in a system. The one grand mistake will insure disaster. Only the return to the basic philosophy of the importance of the individual will maintain success. This requires courage, vision and faith. Decentralization of authority and responsibility which will foster the self development of the individual, and utilize the drive of his motivations, becomes mandatory for continued success. In history there has always been a David to conquer a Goliath.

Within the historical experiences of associations of men, this pattern unfolds again and again. The experiences of the Jews under the leadership of Moses, the pattern of development of the Russian Communists, the evolution of giant corporations in America serve to point out, to the discerning, certain buoys and reefs which have been charted over and over again.

MOSES WAS OUR FIRST LEADER

After Moses had led the Jews from Egypt and had arrived in Sinai, God gave him the Ten Commandments, and amplified them through personal meetings. As had been his practice in Egypt and on the desert, Moses sat in judgment for the Jews every day. Soon, he was sitting from morning till night, listening to each person who was fortunate enough to gain audience with him, and advising each in a personal direct manner. Explaining the importance of his work to his father-in-law, Moses emphasized that he had to settle every disagreement himself, and make known to each Jew God's decisions and regulations. Obviously, in his mind, there could be no room for error in these matters, for they were high level decisions, and required high level implementation. What could have been more logical?

To his more discerning father-in-law, Jethro, nothing could be less logical, for he answered:

> "You are not acting wisely. You will surely wear yourself out, and not only yourself but your people with you. The task is too heavy for you alone. Now listen to me and I will give you some advice, that God may be with you. Act as the people's representative before God, bringing to Him whatever you have to say. Enlighten them in regard to the decisions and the regulations, showing them how they are to live and what they are to do. But you should also look among all the people for able and God-fearing men, trustworthy men who hate dishonest gain, and set them as officers over groups of thousands, of hundreds, of fifties and tens. Let these men render the decisions for the people in all ordinary cases. More important cases they should refer to you, but all the lesser cases they can handle themselves. Thus your burden will be lightened, since they will bear it with you. If you do this, when God gives you orders you will be able to stand the strain, and all these people will go home satisfied."

Moses followed his father-in-law's advice. He explained to the Jews that once he could carry them alone. But now God had blessed them and that they were as numerous as the stars in the skies. They had become a crushing burden upon him from numbers alone, and by himself he could no longer cope with their constant bickering. He ordered them to choose wise, intelligent and experienced men from each of their tribes, so that he could appoint these as leaders. He gave these men the commands which were to be fulfilled. He advised them to listen to complaints among their kinsmen, and to administer true justice to both parties even if one was an alien. In rendering judgment they must give ear to the lowly and to the great alike, fearing no man for they represented God himself. And finally, he ordered them to refer to him only those cases which were too hard for them. He would hear those.

The complexities which arose, as the Jews had grown until "they were as numerous as the stars in the skies," had not passed unnoticed. But Moses hadn't understood the basic problem. Bickering and discontent grew. Frustration increased to the extent that Moses had looked upon his peoples as a crushing burden. If the solution appears obvious to us now, it was no less courageous then. For the survival of God's chosen people was the stake!

These are the buoys which Moses charted for us:

1. Establish a simple, clearcut chain of authority of the individuals within the organization.
2. Place authority to make decisions as near as possible to where the action takes place.
3. In delegating the full responsibility to carry out commands (policy) to individuals, gain a complete understanding that they acquire the complete authority formerly held above.
4. Require that only matters which are difficult or very

important, in the *subordinate's* judgment, be referred to the senior for decision.

5. Insure that the men who are selected for leaders are wise, intelligent, experienced, trustworthy and God-fearing. This implies that if they should prove not to be, they must be removed.
6. Faith is required that men will have the capacity and courage to make sound decisions in the majority of cases.
7. Realization is required that the aggregate results of many individually sound decisions will be better than centrally planned and controlled ones.

THE FORD MOTOR COMPANY

The biggest war which has ever been fought on America's industrial front in our lifetime was no less serious to the opponents than is our present struggle to maintain superiority over the Russian military machine. To some extent it was a struggle for an American Way of Life—autocracy versus diffusion of authority in the way we work. The battle was fought with Fords and Chevrolets. Every salesroom was a battleground. Victory was limited, but only because Mr. Ford could no longer carry on his campaign. He died before he may have been forced to liquidate a part of his fortune. His successor hired the generals away from the enemy, the General Motors Corporation.

Mr. Henry Ford was a genius. He started with an idea, a car, and a small amount of money. By the technique of manufacturing a standardized car, of simple parts, on a production line which required little skill of individual workmen, he revolutionized America. He met the dissatisfaction of his workers, who complained about the monotony of their work, with the most direct remedy he knew. He paid them more than they could earn elsewhere. He made cars cheaply. He sold them for a small profit, and amassed a fortune in the process. From the beginning to the end, the idea, its development and its rapid expansion —the whole scheme of accomplishment rested in his own mind. Self-sufficiency became a mania—duplication a sin. Soybean plants, rubber plantations, steel mills, railroads, ships and a myriad of other activities bore the nostalgic signature we all remember. But as the company grew into a corporation, Mr. Ford did not grow with it.

He gave his executives no real authority. He was the boss of everything. He hated cost accountants, and as a result had accounting but no controls. Purchasing many times bore no relation to production. Production too often was not keyed to sales. By 1945 the Ford Motor Corporation was losing ten million dollars *every month*. The small company grown large was dying of the same sickness that had afflicted Moses. Mr. Ford didn't understand the problems caused by bigness. His mind was obsessed by things, not people. As soon as he retired, his successors hired General Motors executives from the enemy. If they hadn't, Ford might well be one of those names we associate with products that were born, blazed into brilliant success and died — because a man had a dream and couldn't grasp the complexity of success.

What was the power and effectiveness of the General Motors Corporation, that it was able to force this showdown battle for survival? Since its inception in 1908, General Motors has been able to simulate the flexibility of small business, even while producing a highly diversified number of things on a huge scale. Thirty-five divisions each design, develop, manufacture and sell its own product. Each division makes its own purchases of materials and component parts. Even when a "brother" division makes the product needed, another may buy from the source which can furnish the most suitable part or service at the most reasonable price. Each division develops its own manufacturing processes and methods; hires and trains its own employees; develops and maintains its own staff and operating organization, including its own specialists. The general manager of a General Motors Division is completely responsible for building his own organization, coordinating all efforts, and planning the progress of his "company."

General Motors has been able to delegate full authority and responsibility to each division general manager because the Corporation contents itself with issuing clear-cut policy. An upward flow of fact and opinion is insured through a policy committee organization at the top. The operating executives have actual membership upon these committees. Service executives, too, sit upon the committees and thus influence the policy decisions of the company. They also advise, but never direct the Division executives. From top to bottom, there is one clear-cut chain of command, with clear-cut responsibilities welded with full authority. A larger number of men develop ability and initiative, since day-to-day decisions must be made independently of the corporation level. Success or failure is clear-cut and pinpointed. It is measured, of course, by the ability to blend manpower, materials and machines so effectively that a product may compete with another in the public battlefield.

These are the strengths which almost undermined Ford. Emphasis is on people. Duplication is considered to be a blessing. The single manager concept for Buick, Delco and Frigidaire would be unthinkable. One slogan is repeated and repeated throughout the Corporation: "Give a man a clear-cut job and let him do it."

By the time that Mr. Ford retired because of ill health, he had charted some salient reefs for us to avoid:

1. Too much concentration of power at the top may cause an unbalance of effort. It will be difficult, if not impossible, for all individual activities to strive for the same objective.
2. Single managers, at the corporation level, may breed activities which are not contributing to the effectiveness or economy of the corporation as a whole.
3. A large complex corporation, managed with detailed

direction from the top, cannot compete with a small, well organized division, which is aided by the research efforts of a parent corporation.

General Motors added to the buoys charted by Moses:

8. Subordinate operating executives should be formally included in the planning process and in the policy making forums of the organizations.
9. Service executives should be included in the planning and policy making process within the organization. Thereafter they should give advice, but not directives, to the subordinate operating executives.
10. Individuals will more rapidly develop ability and initiative when top level executives issue clear-cut policy, but hold subordinate operating executives completely responsible for the entire accomplishment of the objective.
11. Competitive duplication is not necessarily an evil, and may in fact promote economy and effectiveness within the entire organization.

THE GENERAL ELECTRIC STORY

The management tradition of the General Electric Corporation grew with the company from its beginnings in the Nineteenth Century through its mushrooming growth to a billion dollar business in the booming forties. Charles A. Coffin, the founder, ran the infant company like an autocrat. His successor, Edwin Rice, did likewise. Then in 1922, Mr. Gerald Swope inherited the presidency and for the next decade and a half personally directed the company to success. By 1942 it had its problems. Managers at the high executive level had built huge plants, but had not equipped them with enough machinery to keep productivity abreast of the times. Appliances were designed without the aid of the marketing men. Quantities to be produced were determined by individuals far afield from the marketing personnel. Important problems developed, but it took so long for them to reach the top that objectivity was lost. Mr. Swope had good and sound ideas. He couldn't get them down to the men who could put them into practice. Management down under was functionalized, with no one having the full responsibility for the profit position of a particular product. At the top was a cluster of men, each a master in his field. Finally, in 1944, Charles E. Wilson and Ralph Cordiner set about to revitalize the Corporation. The task was slow and heartbreaking, but the fact that General Electric now has its eyes on a six billion dollar sales goal is a tribute to their success.

The basic problem confronting the men was not merely the size, but the fantastic diversity of the Corporation. They literally fragmentized it into operating departments, each so independent of central authority that their chiefs could act on any operating question, whether it be marketing, design, manufacturing, or selling. Only long term planning and research was retained at the corporation level. By 1952 there were twenty divisions, containing seventy independent operating departments. Functional centralized direction of engineering, manufacturing, purchasing and the like had been abolished. In its place was a new corporation organization called Services, which spent most of its time on long range planning and forecasting. The Service division executives advised the operating managers of new methods developed in other parts of the corporation. They had no power of direction.

Top men no longer needed large staffs. They were enjoined from issuing detailed solutions to the problems of the subordinate operating executives. There was no long fine list of directives, which spelled out in detail what a Division Manager might do, and thus be safe within those boundaries. There was a short list of things he was forbidden to do. At each level executives were left wide open to make mistakes, but never thus directed to make the one grand mistake. Officers for the first time in the Corporation's history were confronted with the full responsibility for making their own decisions in regard to the product they were associated with. A major premise of Cordiner's theory of diversification was that each department must be engaged in a business that was "simple enough for one man to get his arms around." Emphasis is on people.

General Electric sums up its success story in its own words, and adds to our list of buoys, some of which parallel closely those of Moses:

12. Get the greatest and most directly applicable knowledge into play on the greatest number of decisions.
13. Real authority is delegated—but not if details have to be reported or checked upon first for approval.
14. Faith is required that men will have the capacity to make sound decisions in the majority of cases.
15. The main job of service components is the providing of help and advice through a *few* experienced people.
16. General objectives, policies, plans and organization structure must be known, understood, followed and measured. But definition of policy does not necessarily mean uniformity of methods to carry them out in decentralized operations.
17. Executives must realize that authority generally delegated by them to lower echelons cannot in fact also be retained by them.
18. Responsibility, with decision making authority, must be truly accepted and executed at all levels.
19. Personnel practices must be based upon measured performance and enforced standards. Removal for poor performance is required.

LISTEN TO MALENKOV AND KHRUSHCHEV!

In the Communist system all economic activity is planned. The National Economic Plan outlines the tasks to be accomplished during the period in question, and directs the allocation of all resources toward the achievement of the desired goals. It describes the total national income objective and the volume of production of all major commodities. The plan specifies the division of the national product between investment and consumption, and even specifies the relative share in consumption to be enjoyed by every significant group within the population. The Russian

plan is a gigantic comprehensive blueprint which attempts to govern the activities and inter-relationships of all persons and institutions within the U.S.S.R. The plans have the force of law. Change is not merely "allowed," it is *imposed*.

There is a certain lure in the Russian management system, especially to those who are orderly, opposed to waste, and in a certain distorted sense, idealistic. In theory, there is none of the uncontrolled and wasteful duplication of effort which is characteristic of the American system. There being no reason for competition, the laws of supply and demand do not appear to be of any importance. Everything may be planned by an expert, in such detail that all talents may be used and distribution of the product planned according to the needs of the people, as differentiated from their demands. A clear-cut functional chain exists from the Ministry to the peasant, so that no decision may be misinterpreted. No mistakes should be possible. There is no question that the management system is clear-cut and direct. In theory it is most difficult to refute. The only sacrifice is the loss of personal liberty—or from the Russian viewpoint, the elimination of human selfishness. Emphasis, of course, is inherently on materialistic *things*.

The policy of distorting natural growth has imposed terrific handicaps upon the Russian. Plants are integrated too highly. They try to be self-sufficient, since any manager who sub-contracts production vital to his own plan fulfillment puts himself at the mercy of another. Factories produce, at staggering costs, not only their main component parts but their smallest ones as well. Duplication is an evil.

Perhaps the worst of the handicaps is that the government, having planned every detail, also has to police every detail of execution. It is difficult for executives to execute into action plans about which they were not consulted, and which may be foreign to their best interests. Central planners have sought for tangible and immediate results. They have been most reluctant to allow resources to be wasted upon such luxuries as power, housing and service facilities. They have caused shortages in consumer "luxuries." They have forced a centralization of industry and agriculture into five relatively small regions, defying nature to match their plan. They have carefully culled the children to educate for their future leaders. But they have been unable to instill flexibility into an economy which looks to above for detailed direction. Central planners cannot substitute their judgment for the market place. They can only insure that inefficiency will not be punished by failure; that big businesses will not grow smaller through mistakes in judgment and decision, nor little businesses grow great in competition. A vast bureaucracy flourishes in this atmosphere.

Malenkov complained:

"Together with the working out of basic assignments, our planning organs often try to define from the center, numerous detailed indicators of the economic activity of enterprises, building projects, railroads, state and collective farms, trading organizations and other enterprises. Since this is done without the necessary knowledge of varied local conditions and possibilities, it is consequently done with insufficient skill. *It is completely evident that such planning creates difficulty in the work of the grass roots, binding the initiative at the local organs.*"

Khrushchev assailed:

"The Bureaucratic structure is unwieldy, including many administrations and divisions which duplicate each other and often do little or nothing. It is not surprising that the ministry fails to show maneuverability and accuracy in directing the local organs, permitting bureaucracy and red tape in solving urgent problems. The ministry is poorly linked with the practical work and is isolated from the collective farms. Not knowing the true state of affairs in each locality, *the ministry nevertheless tries to regulate from the center all aspects of the activities of local farm agencies, and collective farms, giving instructions for which there is often no need in the localities.*"

The *New York Times* on February 17, 1957, described the inevitable Russian reaction to this state of affairs. The Soviet Union has undertaken a major overhaul of its economic system including fundamental changes in planning, administration and organization. Decentralization of industrial and agricultural controls is the key element in the new program. It will necessarily mean significant movements of personnel and widespread relocation of government agencies. Elimination of many specialized ministries was forecast.

The new plan announced by Nikita Khrushchev called for reorganization of the Soviet economy on the basis of regional economic units. It would replace the present system of centralized control through specialized ministries and departments. What the Soviet leaders hope to do is to eliminate much of the red tape and bureaucracy that have hampered efficient operation of the industrial and agricultural machine. Khrushchev complained that there had been widespread duplication and competition between neighboring plants belonging to separate ministries in purchasing materials, arranging transportation, and many other fields. Departmentalism had led to loosening of normal territorial contacts between enterprises of different branches of industry.

The Russians have encountered many of the same reefs which were pointed out for us by others:

4. If organizations plan every detail at the top, they must also police every detail of execution from the top. The importance of the individual becomes subordinated to the system developed by vast Bureaus.
5. It is sometimes difficult for executives to translate into action plans which conflict with their local objectives.
6. Centralized planning, if done without *complete* knowledge of local conditions and possibilities, may create difficulties and bind the initiative of individuals in the lower echelons.
7. Agencies which try to regulate in detail from the top all activities of the local echelons, may issue directives which are neither needed nor wanted by them, and inevitably will hamper the efficient and effective operation of the organization as a whole.

8. Change, in a centralized system, may become "imposed" rather than allowed.

These are the Buoys and Reefs which have been charted for us by others who have preceded us. We may view them as warnings of laws of cause and effect in our executive direction. One salient fact stands out. Whenever we view people as resources to be controlled we are sailing directly toward a reef. When we see them as individuals, worthy of our faith and trust, and confident that they will devote their intelligence and initiative to strive for a common objective, we tend to follow the buoys.

Which do you follow in your day-to-day actions? The Buoys or the Reefs?

A photographic device which uses the heat or infra-red radiation emitted by the subject has been developed as a night vision aid under the sponsorship of the U. S. Army Engineers. Called the Thermograph, the infra-red device, unlike conventional photography, does not require sunlight or artificial light to produce an image. It depends solely upon radiation from the person or object at which it is focused. Since these radiations are present night and day, it can operate in total darkness.

The Thermograph was developed by the Barnes Engineering Company of Stamford, Connecticut, as a research instrument to determine the basic characteristics a military thermal imaging device should have. Such devices are expected to provide a means for night reconnaissance, terrain mapping and target location. Another military use may be the detection of camouflage.

In operation, infra-red radiation is collected by a scanning optical system and focused onto an infra-red detector. The electrical signal caused by the radiation on the detector is compared to a preset reference level. The deviations above this level are amplified and used to modulate the light output of a glow tube, which forms a thermal image of the scene on photographic film in a Polaroid Land camera for quick development. It has a resolution of one solid milliradian.

—Press Release,
U. S. Army Engineer Research and
Development Laboratories

The development of air-supported surface vehicles has been undertaken by the Ford Motor Company, under the charge of Dr. Andrew A. Kucher, vice-president in charge of engineering and research. Dr. Kucher first proposed this concept of transportation in 1928.

Information released concerning the present efforts center around the possibility of vehicles traveling on rails. The vehicles, called "Glideairs," are supported on air cushions. Devices for producing such cushions for a rail-borne vehicle have been designed. Calculations indicate that about 50 horsepower are required to support a ton of weight. An additional 40 horsepower will move the vehicle about 100 miles per hour. Since the vehicle does not require wings or control surfaces as does an aircraft, it is not penalized by the drag associated with such lifting surfaces. The vehicle is propelled by the jet exhaust of a gas turbine, which also supplies the necessary quantities of gas for levitation.

—from MODERN POWER
September, 1958

A report has been issued describing the circumstances of a turbo-generator accident at the Calder-Hall Nuclear Power Station in June of last year. The casualty occurred during an emergency reactor shut-down. The turbine operator's first warning of abnormal operations was a speed increase—presumably occurring as the generator load was being shed in connection with the plant shut-down. Attempts to manually shut off the steam supply to the turbine were unsuccessful, and the machine continued to over-speed beyond control. Violent vibration of the set, accompanied by flames from the generator preceded the final break-up. As the machine disintegrated, major pieces of the rotating parts remained within the housings, but some large pieces were ejected and caused other damage.

An investigation board concluded that this unusual casualty was caused by the coincident failure of two valves to function automatically. Parts of these valves had been scratched and scored by solid particles which inadvertently had been left in the system on assembly in spite of strict safeguards to prevent such occurrence.

—from MODERN POWER
October, 1958

The development of a light amplifier for military application has been announced by the U. S. Army Engineer and Research Laboratories. The device is designed to aid night vision by amplification of the star-light, or sky-glow, falling on the objective. The light, normally of an intensity so low as to be of no value to the unaided eye, is amplified by the instrument sufficiently to produce a distinguishable image. The heart of the device is a cascaded image tube arrangement, consisting of two tubes working in series in conjunction with an optical system. A 25,000-volt power supply is provided by an arrangement of transformers and transistors taking current from a six-volt battery.

—Press Release
U. S. Army Engineer Research and Development Laboratories

"U.S. NAVAL INSTITUTE PROCEEDINGS"

RESEARCH NAVY

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This article was written by Captain W. D. Brinckloe, USN, an Engineering Duty Officer and Head of the Department of Marine Engineering, U.S. Naval Academy. Reprinted from the December 1958 edition of "U.S. Naval Institute Proceedings"; *Copyright 1958 by U.S. Naval Institute.*

THE OCTOBER, 1957, launching of Sputnik clothed defense research overnight in a mantle of such glamour and urgency that every public figure who could reach a podium started lambasting the military for not having done enough in the past and exhorting it to do far more in the future, to the point that every schoolchild today is demanding all kinds of research on satellites, on ballistic missiles, and possibly on a few other aerial wonders that he can't name at the moment. But neither the schoolchild nor his father could have advised us, a few years ago, that satellites and missiles were the items to push. In 1945 even such an eminent authority as Vannevar Bush was telling the Senate, relative to the feasibility of intercontinental missiles, "If you were talking about 400 or 500 miles, I would say by all means . . . but 3,000 miles? . . . I think we can leave that out of our thinking." And who among us, back during the Korean war, was far-sightedly urging his congressman to pour money into satellites? It takes exceptional vision to look ahead and say that satellites, or missiles, or "anti-gravity machines" should be developed all-out, until research in the basic fields that make such hardware possible comes up with the requisite scientific truths—and then these truths may be so unexpected that they dictate the development of totally different end products.

In this kind of broad gauge research, undertaken in the spirit of true scientific inquiry, the Navy has been a pioneer throughout its history and operates in the same tradition today.

The Navy historically has been the service associated with science. In 1825 President John Quincy Adams requested Congress to establish a Naval Academy "for the formation of scientific and accomplished officers." Five years later the Naval Observatory and Hydrographic Office were founded jointly as the Depot of Charts and Instruments, which under Commander Matthew Fontaine Maury, initiated the fundamental studies of wind, currents, and the paths of storms and helped found the science of oceanography. In 1838 a University of Pennsylvania professor of chemistry and physics became the Navy Department's first scientist. In mid-century the Navy pioneered in bringing on the age of steam, and in the latter part of the century began research that was to convert the world's warships to liquid fuel. In 1915 the world's first transatlantic radiotelephone system was set up between the U. S. Naval Radio Station at Arlington and the Eiffel Tower in Paris. In 1923, the Naval Research Laboratory was founded to conduct research in the physical sciences; most famous of its initial projects was investigation of the phenomenon later known as radar. This laboratory in 1939 instituted the nation's first organized research program in nuclear energy.

Then came the war, and mobilization of the nation's

scientific potential for victory. And promptly at war's end the Office of Scientific Research and Development withdrew all research support and went out of business. During the latter stages of the conflict, thoughtful naval leaders were realizing more and more that without all the new military hardware born of our pre-war store of basic scientific knowledge (largely European in origin) we could well have been defeated, and were planning how to nourish a home-grown research effort. In May, 1945, the Secretary of the Navy created an organization which had its genesis in OSRD and was destined to become of unprecedented importance to this nation's basic research program. Born as the Office of Research and Inventions, and established by Congress the next year as the Office of Naval Research, it was the first agency of government with the express purpose of supporting and coordinating basic research.

Its success was overwhelming. Suspicion of military domination of science was dispelled, and ONR became the model of future governmental organizations for support of research—NSF, OSR, OOR and in part even the mighty AEC. The Universities of Chicago and California, asked if they would enter into research contracts with the new Navy organization, accepted with the comment that this was the wisest proposal for research ever voiced by the government. An early issue of *Fortune* said, "Smartest and most carefully organized of the new military agencies is ONR—which is spending about $20 million a year chiefly among universities for pure research, with no strings attached and a maximum of freedom for the working scientists. Without this support, basic research in the U.S. would be at its lowest ebb in history." MIT's Vice President Killian, now the presidential advisor, said, "The Navy has shown not only how to write research contracts but how to manage research. The ONR represents an extra-ordinary achievement in successful and enlightened government research."

At the dedication of Johns Hopkins' Applied Physics Laboratory, Dr. DuBridge said, "We will forever owe a debt particularly to the Office of Naval Research for what was done." Last year Professor I. I. Rabi, distinguished Columbia University physicist, stated that the current general health of research in universities and elsewhere was largely due to ONR's efforts. And a recent *Fortune* article on defense research said, "The Office of Naval Research is outstanding—indeed, most scientists would rather deal with ONR than with any other government agency, or even a generous private foundation."

The scope of the Navy's total research and development effort, traditionally not publicized, includes employing one third of all the R&D people in the entire government plus directing 80% of ONR's funds to the contract support of basic research in the universities. (Outside the AEC's special province of nuclear physics, the armed forces as a whole sponsor half the basic research in American universities and technical institutes—and even in nuclear physics the ONR carried nearly the entire load of research support until the AEC was established in 1948.) In the years since the war, ONR has supported half the students who have obtained doctorates in the physical sciences in this country—perhaps 2,000 for last year alone. It is not surprising that the billet of Chief of Naval Research has been authoritatively labelled the most important scientific post in the armed services.

What is the secret of the Navy's success in a field so fraught with pitfalls?

The answer is two-fold, with the first part arising from the second. First, the Navy has realized that research is a long-term peace-time activity, and that it must be stimulated but cannot be directed. In other words, it must be continuous and must lie wherever the competent scientist looks. But how can the Navy finance research in such random directions? That leads to the second half of the answer, which is that the Navy's far-flung operations on and under the sea, in the air and on the land bordering the sea bring it into contact with every environment from ocean depths to farthest space. Geography, acoustics, engineering psychology, statistics, geology, power, physiology, astro-physics, marine biology—there is little in the physical world which doesn't concern the Navy. So when the war spot-lighted this need for large-scale peacetime support of basic research, something never before undertaken by our government, the Navy was uniquely prepared both by its scientific tradition and by its involvement in virtually every major scientific field, to play a pioneering role.

How does ONR stimulate research? Any scientist with an idea that needs looking into and a reputation in his field just sits down and writes ONR a letter, saying in plain English what he has in mind. If it sounds interesting, they work up a contract along the lines he has proposed. But it's never cut and dried; if the investigator reaches midstream only to find out a shift of direction is in order, ONR is usually glad to modify the contract to suit. Then when it's time for the report—the product ONR is buying—nobody's fussy about that either. If the results have been published in the scientific literature (an action ONR encourages), a reprint of that will be fine. Small wonder, with this free and easy arrangement, that scientists find ONR an agreeable partner.

Does it all sound too pat—a good way to waste government money in halfbaked studies? There's really not much danger. The universities are proud of their reputations as centers of basic science and refuse to certify proposals of dubious worth when asked by ONR to countersign the contract. Second, scientists of the caliber backed by ONR want neither to waste their time on, nor to publish the results of, trivial investigations. Finally, and this is perhaps most important of all, the research subjects are

selected by the right men—the scientists who know the field. As C. E. K. Mees of Eastman Kodak puts it: "The best person to decide what research work shall be done is the man who is doing the research. The next best is the head of the department. After that you leave the field of best persons and meet increasingly worse groups. The first of these is the research director, who is probably wrong more than half the time. Then comes a committee, which is wrong most of the time. Finally there is a board of company vice presidents, which is wrong all the time."

All this is fine. But isn't the Navy really, under the guise of scientific freedom and its broad interests, just funding every "good research" project under the sun that someone with a reputation wants to investigate?

The Navy is fortunate to have a corps of scientists of first rank, who work with advisory groups and consultants in every field to determine research areas of probable naval interest. The decision on whether to support or not to support is based ultimately on whether a potential project fits into one of three broad categories:

First, scientific areas extremely important to future naval readiness, but of little present interest to industry. The Navy usually is the only agency who will fund these areas, and sometimes also has to stimulate interest among the scientific community to get some research started. Certain important astronomical and high-altitude coronograph work has fallen into this category.

Second, areas of importance both to naval technology and operations and to industry. Solid state physics research, whose present high level of activity is due greatly to consistent ONR support, falls into this category.

Third, areas where potential naval interest looks unlikely today, but where modest support assures that we stay aware of developments and can exploit them rapidly if possible applications show up. And show up they do, as witness ONR support of low temperature physics or cryogenics, considered by many outstanding physicists to be the finest example of government-sponsored academic research. The union of cryogenics research with subsequent solid state research led to revolutionary consequences that laid the foundation for much of the work on the hydrogen bomb. And just three years ago ONR began probing the apparently most unpractical field of radio astrophysics, the study of solar emissions; already this *pure* research has contributed substantially to naval navigation and communications, including development of a "radio-metric" sextant as accurate through clouds as the optical sextant is on a clear day.

The wisdom of ONR top scientists in nurturing these and other ideas was gained in consultation with the Naval Research Advisory Committee, a group of fifteen leading American scientists—presidents and vice presidents of research of U.S. universities and industries.

The Navy has sponsored some top-notch people—and their results show it. Three physicists under ONR contract have received Nobel prizes for their work. The American Mathematical Society's Bacher prize, awarded only once every five years, has twice gone to ONR contractors. An investigator on a long-range ONR radioastronomy program has received the gold medal of the British Royal Society. Three past presidents of the highly regarded American Psychological Association have been principal investigators on ONR contracts.

RADIO

Radio communications is an excellent example of the Navy's research at work. At first blush the subject sounds old-hat—everything worth discovering was dug out long ago, and all that remains is to refine the art here and there. It's lucky they didn't leave it at that, or a fistful of exciting new discoveries would still be in limbo.

For example, lots of Navy attention is going to the improbable art of transmission by means of radio signals reflected from the trails of meteors entering our atmosphere. Known as "meteor burst" or scatter, this seemingly ridiculous process is expected ultimately to become a vastly improved medium range communications system. Then there's "whistler mode" transmission, wherein signals go from Naval Radio Station NSS at Annapolis to the point in southern Chile where the magnetic lines shooting out from Annapolis come back again to earth. The phase and amplitude of these signals when they hit Chile indicate that they have ridden the magnetic lines out for a distance of several earth radii and back again. "Whistler mode" is important in showing that the ionosphere is not opaque to very low frequencies, and also in demonstrating—most significant for long range electronic navigation systems—that the earth's north-south and east-west characteristics are very different for this purpose. And there are those ubiquitous radar signals that NRL has been bouncing off the moon for the past six years. These continuing experiments, which have included round-trip voice transmissions, show that Luna is an effective radio relay station for many types of communications. If the New York overseas circuits are busy, just route your call via the moon!

Radio must include radioastronomy—the new way to look at the universe. The Navy has been a leader in this field since 1946, when NRL astronomers started turning their big radio-telescope on the sun, the planets, and "radio stars" so distant they show no trace on optical telescopes. Based on the discovery that heavenly bodies send out radio signals just as they do light waves, this new science has in a scant six years "shown" us by radio waves nearly the entire spiral of our own galaxy, hidden from optical view by interstellar dust since the dawn of man. The

visible spectrum has been a small and dirty window into space—our own atmosphere and the debris floating in the void make a murky medium through which astronomers have peered hazily for 300 years. Now radioastronomy has opened the much larger and cleaner radio window, and tremendous finds are floating into view.

The mighty sun emits light waves too blinding to look upon, heat waves that blister flesh in a few hours, and radio waves of presumably equivalent magnitude. These great forces come from the awe-inspiring thermo-nuclear furnace in the fiery center, mightiest reaction within our ken. By contrast, at night the most powerful telescope can show you ever so faintly two little wisps of luminescence that astronomers identify as the Cygnus A Galaxy, 270 million light years distant. And this impossibly remote speck in the telescope pours just as much radio energy on the earth as does the thermonuclear sun, eight light *minutes* away. What titanic power source can so dwarf our solar H-bomb? It may be that Cygnus A is really two immense galaxies, one composed of conventional matter and the other of "anti-matter" (protons and "anti-protons," as physicists have shown recently, will annihilate each other on contact with the production of great amounts of energy; and there is a theory that in widely separated parts of the universe all the separate particles and their anti-particles may be in continuous creation); and that their collision is releasing energy beyond our comprehension. This theory is reinforced by the spectroscopic finding that even the widely dispersed interstellar hydrogen within Cygnus A, rather than being at a temperature far below 0° as in ordinary galaxies, is excited up to 10,000° C.

Naval Research Laboratory investigators were the first to measure the velocities at which distant galaxies are receding from earth, when they peered at Cygnus A through their radio-telescope. They figured these radio waves would be partially absorbed by the characteristic frequency of interstellar hydrogen in the galaxy, leaving a little dip in the spectrum at this point—or at a slightly lower frequency from doppler effect if the galaxy were receding. This gave them a receding velocity of 10,000 miles per second, very close to the velocity previously estimated from the observed "red shift" in the visible light—and reinforced the imaginative theory of the expanding universe. These are strange and wonderful uses indeed for the humdrum old science of radio.

Something else cooking in radio is ONR-supported solid state research which recently came up with the "maser." The random electron motion in radio circuitry causes internal noise often 5,000 times as loud as the tiny radio signals from the stars. With the maser, a micro-wave amplifier depending on molecules rather than electrons for its action, internal noise is very low and detection ranges for radioastronomers may be 100 times as great as at present. It is now being used in NRL's telescope, with remarkable results. In addition to multiplying the extent of our new boundaries in the universe by 100 at one stroke—no small achievement—this Navy discovery promises similar radical improvement in radar ranges; and that brings it close to home in a hurry!

A Navy-sponsored research study at the University of Illinois on the properties of semi-conductors has supplied much of the basic information that has made possible the development of diffusion transistors, which not only can be mass-produced but can operate at much higher frequencies than older transistors. And Navy research, developing silicon and germanium in the search for a substitute for rare selenium, actually ended up with devices better than those made from selenium.

There's another Navy-produced stir in the radio business, one that promises to end up right in your house. In a recent attack on the growing maze of dials and gauges that faces the bewildered pilot while his speed goes up and reaction time shrinks to the vanishing point they are evolving a tremendous little computer that will paint a pictorial display summing up the information the dials want to tell him at a glance. And to make it possible in daylight and crowded cockpits, NRL is developing a flat picture tube with a special transparent phosphor that reflects little light and hence not only can be viewed in bright daylight but can be seen through as part of the windshield! A by-product of this remarkable device probably will revolutionize your home TV set. It can provide a simpler and more efficient color television tube and is expected to lead to the development of 3-D television as well.

BIOLOGY

Let's shift to the field of biology, a science in which you would think the Navy's research interest would be slight—outside of the fact that it has close to a million men in uniform and is interested in their health.

The Navy is making notable progress in finding ways of preserving such tissues as blood vessels, skin and bones, so they can be placed on the shelf and be available for transplanting in severe wounds. The sight of a Navy surgeon pulling an artery out of the deep freeze and installing it in place of a damaged section, just as a mechanic sticks another bearing in your car, is worth waiting for. Fascinating new discovery, too, is the fact that the skin of unborn calves is astonishingly effective for severe burns. Not grafted on, but wrapped on like a bandage, this embryonic bovine skin lets the human skin grow back underneath without the scarring and repeat grafting found with the use of human skin. And the beautiful thing about this dressing is its availability.

Navy researchers are looking into such unlikely things as the habits of desert birds, to see how their innards can get along on so little water. Perhaps we can find clues to help stranded mariners adrift on a

life raft, or fliers down on the desert itself. And at the other end of the atlas, they are trying to learn the penguin's secret in keeping her eggs toasty warm and hatching them in polar cold. Maybe the penguin, in addition to helping sell cigarettes, will give out with some tips on how to keep navymen operating in the frigid environment of the polar regions or the ramparts of space itself.

Then there are fish. We would do much to emulate the jet propulsion system of the lowly squid, and so he comes in for a hard look. And unfortunately for him, he has another handy feature—his nerve cord is just the size for lots of good experiments. As a result, a bewildered but happy group of Chilean fishermen spend the days profitably combing the reefs for squid, and off goes a big refrigerated crate of them to the U.S. Navy three times a week.

Other undersea dwellers can do what the Navy wishes it could do—specifically certain fish which swim a good deal faster than they have any theoretical right to do Biologists cut them up, and from their muscle dimensions compute the power they have available; then they clock them over the measured mile (not the cut-up ones, but their cousins), and they're going too fast. It's not their shape—when the investigators freeze them solid and tow these piscatorial icebags in the model basin tanks, they need the full calculated power. Whatever their secret is, they have it only when they're alive and swimming. Scientists are on the trail of a few possibilities: maybe the fish pokes out parts of his stomach here and there in a way that maintains laminar flow that means those extra knots. Maybe it's something else. Whatever it is, the Navy's submarines would like to have some—and some day, no doubt, they will.

For biological snooping into a region once as inaccessible as outer space, the Navy has been sponsoring Professor August Piccard's fantastic underwater blimp, the bathyscaphe. Able to withstand pressures three miles down, this slightly self-propelled craft can take two men and their scientific gear down to 99 per cent of the world's ocean floors. Last summer and fall the novel vehicle made a series of 26 dives down to about two miles off Naples, studying some effects of undersea life on acoustics as related to submarine warfare. Besides their numerous classified observations, the Navy scientists saw lots of life at all depths, including such oddities as fish whose bodies appeared covered with white down, and discovered many indications of burrowing animals on the ocean floor. The discoveries of the exotic bathyscaphe—now at the Naval Electronics Lab in San Diego—are just beginning.

Coming above water for animals who can teach us tricks, the Navy has admired the talented little bat—whose one gram "radar" (actually sonar) set can discriminate targets at 150 feet from background of far greater density. This set is both search and attack, varying its spread and frequency at will as the target's aspect necessitates.

ONR researchers at Notre Dame have developed the germ-free animal as an effective new research tool. On an animal without other germs, diseases caused by specific organisms can be studied with no foreign influences. For the first time it has been possible to prove that bacteria cause tooth decay—a long-held hypothesis that no one knew for sure except the ad-writers—since tests on germ-free animals fed a sterilized diet show they have no dental caries (and probably no fun, either).

A host of other biological investigations have occupied Navy researchers. Their accomplishments include producing the first successful virus in the absence of host cells, successfully testing plastic corneas to replace damaged corneas in animals, developing better shark-chasers, analyzing which food shipwrecked mariners can eat (and how to catch it), developing blood plasma expanders, discovering a revised concept of burn shock with resultant new treatment, developing a family of new agents for the relief of fatigue and pain, the treatment of tension and anxiety, and the promotion of alertness and rejuvenescence, and learning more about the lowly barnacle and how to discourage him.

HIGH ALTITUDES

But all these things, however interesting and beneficial, are right here among us. How about the quest of the century—the race for the stars?

Until man can blast himself into outer space and return to tell about it, he will have to rely on observation posts placed ever higher and higher in the atmosphere. The Navy high altitude program started in 1946, ages ago by today's swift space calendar, and it is owing to that farsighted beginning that we have as solid a store of basic information as we do. In that year the Office of Naval Research initiated its high altitude plastic balloon program, Project Skyhook; at the same time the Naval Research Laboratory began work with research rockets, first with the German V-2 and then with the Viking and Aerobee rocket. Both attacks were necessary, because balloons could remain up for several hours, while rockets could go much higher but could stay only a few minutes. Unmanned Skyhook balloons carried automatic instruments to the record height of 25 miles, and a single stage Viking rocket made a 1954 record flight to 158 miles with an 825 pound payload. This rocket was modified to become the first stage of Vanguard.

Late in 1957, in Project Stratolab, the Navy sent up a 12-inch telescope for an important first in science. This telescope automatically took hundreds of pictures of the sun at 81,000 feet, virtual "close-ups" with the atmosphere's obscuring water vapor left below to permit registering a wealth of detail far surpassing anything ever taken before, and then parachuted safely to earth. Future unmanned tele-

scope flights are in the wind with larger scopes, and it is probable that a television may be attached later, for direct transmission of these spectatcular telephoto shots to the earth.

In the more dramatic manned Stratolab program, a two-man team of naval scientists, Lieutenant Commanders Malcolm Ross and M. L. Lewis, rode their instrument-packed gondola up to 86,000 feet, collecting a wide variety of scientific data plus the Harmon Trophy. Major David Simons of the Air Force, who made his outstanding world's record ascent to 102,000 feet, used a high altitude balloon developed for the Navy program.

Scheduled for November as this went to press is a Stratolab flight by Ross and Dr. John Strong of Johns Hopkins, in which they will take a 16-inch telescope up to the clear medium of 80,000 feet and get the first unobscured look at Mars. They hope to measure the water vapor and oxygen content in the red planet's atmosphere, possibly solving the mystery of her famous canals, and getting clues to the possibility of life itself on our neighboring planet. This ascent, with its new technique of high altitude astronomical observation, is expected by many eminent astronomers to usher in startling advances in astronomy and astrophysics.

Everyone has seen the dramatic photographs of the curving earth, snapped from the rim of the world by a Viking research rocket 158 miles out. Later Aerobee-Hi Navy rockets have soared to 193 miles, record for research rocket. In 1957, NRL rockets made the first quantitative intensity measurements of micrometeors, those particles so potentially hazardous both to earth satellites and to intercontinental missiles streaking through the upper atmosphere. NRL scientists attained early proficiency, not only in the rocketry which now catches the public fancy, but also in the delicate art of telemetering the information back to earth from a rocket high in the stratosphere. It was this early know-how that weighed heavily in the decision to assign the American earth satellite program to the Navy, and has proven so effective in the Minitrack and other radio-intelligence systems.

Using such research rockets as the Navy's Aerobee, Aerobee-Hi and Deacon, scientists have confirmed the theory that radio blackouts come from an extra layer of ionized particles in the upper atmosphere, ten to twelve miles below the lowest portions of the ionosphere. This layer occurs during solar flares, and it has been established that it is caused by X-ray emissions from the sun.

These rockets are playing an important part in the International Geophysical Year. A Navy Aerobee launching crew is stationed at Fort Churchill, Canada, a launching site picked because aurora, airglow, and other desired atmospheric disturbances show up best at the high latitudes. The Aerobee is a reliable and inexpensive vehicle that can reach well into the ionosphere, and the Aerobee-Hi is an improved version for high altitude research; the Air Force also has a version of the latter.

Vanguard has come in for quite a shellacking from time to time. Forgotten when Explorer attained orbit after Vanguard's unsuccessful tries was U.S. satellite history. Dr. Wernher von Braun himself points out that Project Orbiter, the genesis of what became the Army satellite project, was set in motion by ONR when it called a conference of military rocketeers in 1954. The quite feasible joint Army-Navy program decided on then, using existing military rockets, was terminated by the leaders of government in 1955 so that nothing should interfere with the missile program, and Vanguard was born as a brand new research rocket unconnected with military missiles and their secrecy.

Dr. von Braun's generous quotes at the time of the Jupiter-C rocket's success in orbiting a satellite bear repeating: "I tell you quite frankly the Vanguard is a missile superior to this one. . . . It is so sophisticated that it is a little difficult to get it off. Our is based on older and more proven components. . . . Ours is a little more obsolete."

The search for exotic propellants is getting hotter. After World War II the hydrocarbons had about exploited their chemical limit of 19,000 BTU's per pound, and a new chemical fuel was indicated. In 1946 the NACA tried burning boranes, and shortly afterward the ONR awarded contracts to several companies to find out more about the promising chemical. By May, 1952, the basic research had proceeded far enough for the Navy to start Project Zip, the search for a usable borane fuel. The search was so successful that in late 1955 the Air Force came in, and this year the two services will put their second $50 million into borane fuel plants. A Russian plane designer of note states that the boranes fill the gap between hydrocarbons and nuclear power.

Actually the problem is not quite as simple as BTU's per pound. If it were, the Navy's Polaris missile wouldn't be winning so many unexpected converts to its solid-propellant engine. A workable (not necessarily Polaris') solid propellant might have particles of oxidizer in a plain old low-BTU hydrocarbon binder; the catch is that the solid propellant may easily have double the density of the liquid fuel, giving it a lower specific impulse but more overall range. There are of course other solid-fuel advantages, such as reliability, fire-safety, and very short countdown, having no relation to power.

Getting lots of attention are the ultimate propulsion systems, and this article has nothing to say about actual Navy research in this field. But the ballpark of theoretical feasibility includes "simple" atomic rockets, where a uranium pile could heat up hydrogen to many thousand degrees and shoot it out the exhaust for very high specific impulse. Potentially still more powerful would be the "stabilized free radicals," unstable fractions of chemical compounds that normally exist only momentarily in very hot

reactions such as flames before combining explosively, but have been captured occasionally in the laboratory by superfreezing; pure hydrogen atoms reacting to form hydrogen molecules could produce, if controllable, double the specific impulse of an atomic rocket. Free hydrogen radicals float about in the sparse upper atmosphere, and it wouldn't be impossible that a high-flying satellite might cruise along with its front door open, collecting enough to keep putting along in orbit forever.

The current theoretical ultimate, the photonic rocket, once it reached virtually the speed of light, could go out to the end of the universe and back in four billion years which—wait—which might turn out (the scientists divide on the practical results of relativity time-compression inside a space ship) to be a mere forty years or so for the space cadets. They run the risk, of course, of getting back to find that, not only have the girls they left behind grown up and died, but so has the whole human race.

CONCLUSION

It is very hard to stop a discussion of the Navy research program. There is so much variety, and the siren song of interest keeps calling you around the next corner. Completely unmentioned in this article are some fifty developmental laboratories operated by the technical Bureaus, who take over from ONR as soon as basic research proves the feasibility of a development—and who do a good deal of basic research themselves in their own areas of interest. Unmentioned, too, are the big test centers who prove out the untried missiles or machines delivered to them, and in the process do a good deal of creative work on their own. Each of these is a story in itself.

This article has confined itself largely to the basic research program. Some people are surprised that the Navy would do any basic research whatsoever. More are amazed at the breadth of Navy interest in pure investigations. But the overwhelming paradox is that a fighting service, whose heritage is the rugged and elemental sea, has been a foremost supporter and guardian of pure science in this country.

More prophetic than he knew was Maury's comment of a previous century: "Navies are not all for war!"

Two new types of ceramic strain gauges have been announced by Technical Ceramics Limited, a British firm. The gauges are made of piezo-electric ceramic material which combines a wide temperature range with a flat temperature coefficient. The piezo-electric material is said to require less complex instrumentation than does the conventional resistance gauge. One of the new gauges is sensitive to linear strain, and is called an expander gauge. The other is a laminate of the sensitive material and brass foil, which is sensitive to a bending motion. Both can be used to measure dynamic strains, and can thus be used as vibration pick-ups. It is also stated that the gauges can be used, in certain applications, as small transducers to excite vibrations in a member by application of suitable alternating voltage.

—from ENGINEERING
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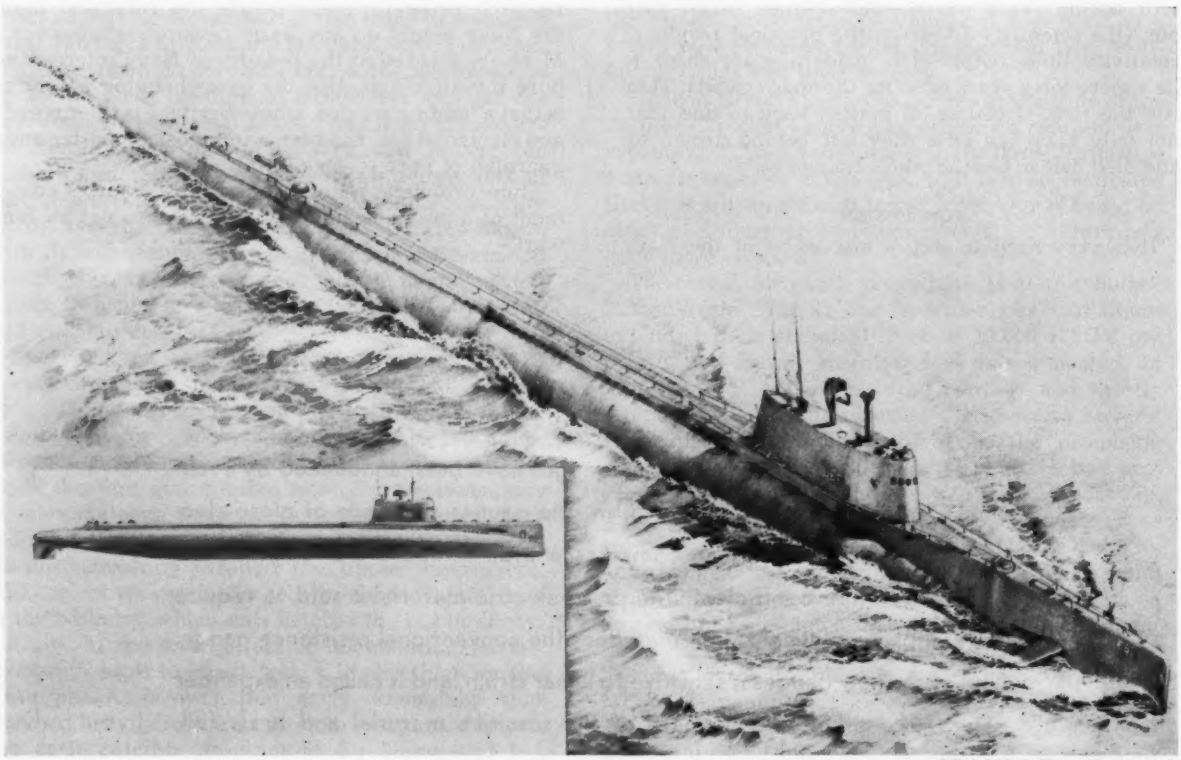


Official U. S. Navy Photograph

Artist's conception of USS *Triton* (SSR(N)-586), the largest submarine ever built. Powered by twin nuclear reactors, the ship was launched in August.

JOHN H. WRIGHT

LONGITUDINAL STIFFNESS OF MARINE PROPULSION THRUST BEARING FOUNDATIONS

THE AUTHOR

is a graduate of the U.S. Naval Academy (1940) and the USNA-PG School. He served in various engineering billets until 1948. Since then he has been employed in a civilian capacity in the Machinery Design and Fleet Maintenance Divisions of the Bureau of Ships, until he assumed his present position as Assistant Division Director in the Navy Management Office in 1957.

THE PROLOGUE

PERHAPS no other organization in the world offers the diversity of engineering billets found in the Navy's Bureau of Ships. It is the agency charged with the design, construction, and maintenance of the United States' Fleet. And a modern man-of-war may be likened to a fortified and extremely mobile industrial city. There is probably no art or science that isn't reflected in the completed warship. After all, naval fighting ships are mightier in some respects than the Grand Coulee Dam; yet as small and sensitive in others as a delicate Swiss watch. Whatever the scientific specialty—there is a corresponding challenge in the Bureau of Ships.

Foremost among challenges is the continuing problem of keeping the assorted ship design experts acquainted with each other's efforts. It's easy to imagine that Solomon himself wouldn't today enjoy the excellent reputation that he does, had he ever been challenged to reconcile the often conflicting interests of the physicists, scientists, and engineers involved in warship design. And the latter is, of course, precisely the problem that confronts anyone having the temerity to discuss main thrust bearing foundations.

THE PRINCIPALS

First, there is the physicist. He is interested in the frequency and amptitude of longitudinal vibration excited by propeller thrust. These are, among other things, a function of the thrust bearing foundation stiffness. He therefore sets about positively determining this elusive foundation spring constant.

Then, there is the hull scientist, an expert on structural mechanics. He is concerned more directly with foundation problems, since he must actually design the supporting members for the components of the shafting system (including the thrust bearing itself), and must moreover provide for absorption of the transmitted propeller thrust by the hull structure. He thinks in terms of dynamic loads and static loads, and bending moments and shearing forces. Still, it's quite possible that he has never worried about the thrust bearing foundation longitudinal spring constant.

Finally, there is the marine engineer. His concepts serve to bridge the gap between the precept of the scientist and the precept of the artisan or craftsman. This is particularly true as regards the problem of providing an adequate thrust bearing foundation. After all, it is the marine engineer who is responsible

for accommodating and arranging the propulsion machinery within the confines of the hull.

THE PURPOSE

While the physicist may desire a specific minimum foundation stiffness, and the hull scientist may design the best practicable foundation under the circumstances; it's entirely possible that neither is aware of what the other is doing. Moreover, as we shall endeavor to show, only the marine engineer can assure that the one can fulfill the desires of the other, by so arranging his equipment as to allot sufficient space for accommodating the proper foundation.

Accordingly, this paper is not intended to serve as a technical treatise for the enlightenment of physicists or hull designers. The literature is already replete with such material. The real problem concerns the marine engineer's failure to fully understand or appreciate his design requirements. Therefore, the purpose of this article is to apprise the propulsion plant designer of the inter-related foundation design interests of the physicist and hull designer; acquaint him in general terms with the basic principles underlying their efforts; and especially, to provide him with a simple but practical design technique which will assure his automatically satisfying their needs and desires.

THE PROBLEM

The longitudinal stiffness of propeller thrust bearing foundations (usually denoted as the foundation spring constant, k_f) is very important in the design of high-powered vessels, particularly those employing propulsion components of large mass coupled to long shafting systems. This results from the fact that the longitudinal frequencies of a propulsion mass-elastic system are (unlike the torsional frequencies) a function of foundation stiffness as well as of the component masses involved. At the same time, the magnitude of the fore and aft thrust of the propellers, plus any margins for fore and aft shock impact, plus (in the case of submarines) the axial hydrostatic load on the propeller hub at deep submergence—all combine to make the longitudinal load on the thrust bearing foundation a most severe loading condition.

Excessive vibration amplitudes in the longitudinal or axial direction of the propeller shaft system may occur when the natural frequency of the system (as determined by the masses of the propeller, entrained water, shafting, and connected gear wheels; and the flexibilities of the shaft and thrust block) is such that resonance is excited in the operational range of propeller revolutions by the thrust alternations occurring at blade frequency. A determination of longitudinal frequencies with relation to the maximum propeller rpm of the vessel therefore becomes an important factor in the design of large high-powered vessels, if unacceptable longitudinal vibration amplitudes are to be avoided. When calculations undertaken in the early design stages indicate that these longitudinal criticals lie in or near the rpm range of the propeller, it is possible to shift the criticals with respect to the propeller speed range by changing shaft dimensions, the longitudinal location of the thrust bearing, the number of propeller blades, or the foundation stiffness.

As regards the thrust block foundation itself, it should be noted that the maximum practicable stiffness is fairly well fixed by considerations apart from the vibration problem, such as the approximate location of athwartship condensers or other large machinery items which interrupt the fore and aft continuity of the thrust foundation. At the same time, while the stiffness of the thrust bearing foundation may greatly influence the calculated critical frequencies, the massiveness of the structure, plus the fact that frequency varies as the square root of the spring constant, suggest that an impractical extent of reinforcement would be required to appreciably shift calculated frequencies. Thus, foundation stiffness is not determined with a view to strengthening it, if critical system frequencies and propeller blade frequency coincide, but rather, it is estimated only as an incidental step in the predicting of natural longitudinal frequencies.

THE PRACTICE

It follows from the foregoing that it usually isn't necessary to know the foundation stiffness with a high degree of accuracy. As a matter of fact, the customary procedure in new design is to investigate the sensitivity of calculated criticals to experimentally determined ranges of longitudinal foundation stiffness, so as to determine the limits of permissible error in the estimated foundation spring constant. It should be further noted that the estimated spring constant is normally derived solely from experimental data previously obtained for comparable installations. Thus, k_f ranges from 5 to 20 million (inch-pounds per radian) for thrust bearing foundations located adjacent to the propulsion reduction gear casing, and k_f ranges from 20 to 40 million for thrust foundations located well aft and separate from the propulsion machinery.

It is fortunate that reasonable estimates of k_f are all that is required, since the flexibility of bearing supports is the most indeterminate factor entering into the calculation of longitudinal criticals. Detailed analysis and calculations of k_f are possible only after thrust bearing mounting, foundation, and propeller shafting system drawings have been developed. This very fact emphasizes again that k_f is not a truly variable factor in the design process. Even in the advanced design stages the calculations, though quite involved, represent only educated guesses, due to the indeterminate nature of the end-fixity of the various members of the foundation, and the resilient nature of the hull of the vessel itself.

Even those experienced in the art of estimating spring constants find the determination of k_f extremely difficult, and widely varying opinions among

the experts are the rule rather than the exception. One famous research organization required a month to estimate k_f for a complete vessel, for which all the physical data were known. A large shipbuilding concern found reasonably accurate estimates of k_f to be impossible, and therefore calculates the variation in frequency for values of k_f ranging from 7.5 to 30 million, which they consider to be representative of the worst and best possible foundations, respectively.

THE PROPOSAL

In any case, k_f can be accurately determined only experimentally, by shaker tests, after a vessel is completed. Nevertheless, an estimated k_f is required in the early design stages for purposes of vibration analysis. Moreover, since substantial improvement in the completed foundation is normally impossible or impracticable, there is even more reason for developing some simple procedure for predicting k_f values in advance of completing a new ship design.

The procedure envisioned should enable the arrangement engineer to advise the physicist at an early stage as to the apparent practicable limits of k_f achievable in a given location for a given design. Again, it should permit the ready evaluation of the relative merits of alternate foundation location possibilities. Above all, it should serve to guide the arrangement engineer, such that he will allot adequate space for the hull designer, with a view to enabling a foundation design that will incorporate the stiffness characteristics that vibration analysis indicates are necessary or desirable.

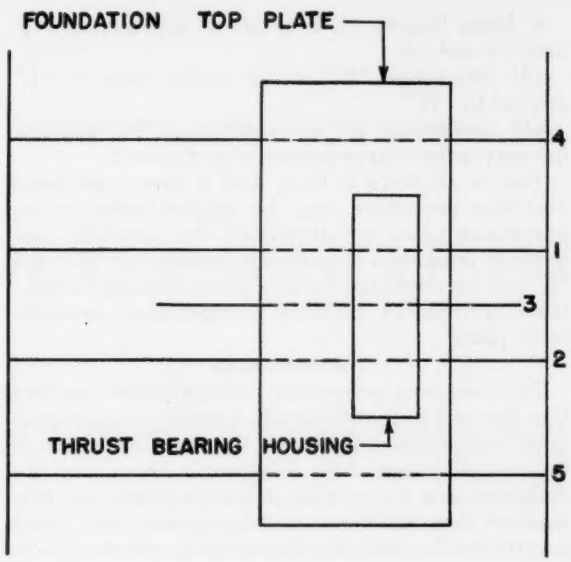
Accordingly, a simple but reasonably valid method for predicting k_f is presented herewith. It should be noted that the procedure described does not apply to those instances wherein the numerical value of "R" (a term to be defined below) is less than approximately 0.33 (at which point bending deflection —which the proposed method neglects—is more critical than the shear deflection). Nor does it apply to those foundation arrangements in which the top plate is extended to and joined with a longitudinal bulkhead or the rising shell of the ship. Furthermore, the admitted accuracy of the proposed procedure is on the order of plus or minus 8 percent. However, the speed of application of the method is considered to far outweigh the limitations on its accuracy, especially in view of the generally acknowledged indeterminate nature of the entire "science" of estimating k_f.

THE PROCEDURE

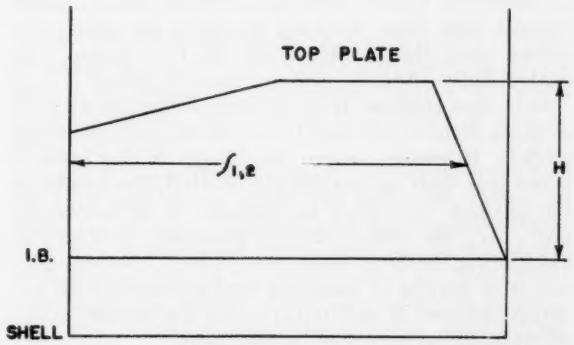
(1) Determine "H," the maximum height of the top plate above the inner-bottom. See Figure 1-c.

(2) Determine "L," the average of the *mean* lengths of all the girders fully effective in shear.

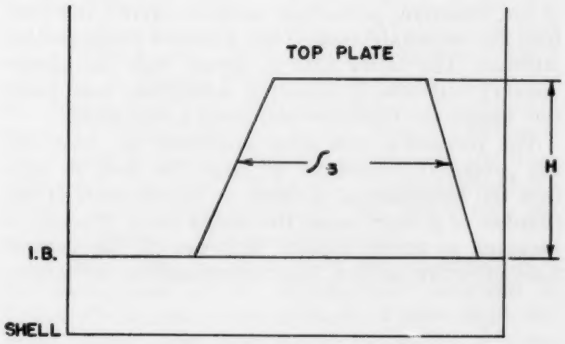
a. Fully effective girders are those that transit directly below the bearing housing, e.g.,—No. 1, 2 and 3 per Figure 1-a.



(a)
Plan



(b)
Elevation (Girders No. 1, 2)



(c)
Elevation (Girder No. 3)

Figure 1. FOUNDATION SKETCHES.

b. Mean lengths (1, 2, 3) are as indicated in Figures 1-b and 1-c.

(3) Determine "R," which is the ratio of "L" divided by "H."

(4) Determine "k_f" as a function of "R," utilizing the appropriate curve presented in Figure 2.

That is all there is to it. And it should be noted that this procedure may be applied even before foundation plans are developed. For example, reasonable maximum practicable values of "H" and "L" can be estimated for any given location directly from preliminary shafting or machinery arrangement plans.

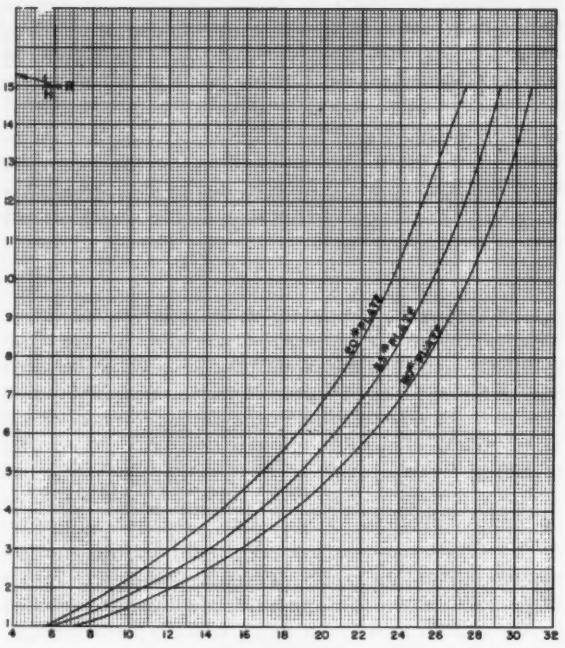
THE PRINCIPLES

The foregoing procedure is based upon the fact that the two principal factors entering into longitudinal foundation stiffness are the shear deflection in the central girders fully effective in shear, and the deflection due to rotation of the inner-bottom. It is realized that additional parallel girders (i.e., those parallel to the centrally located fully effective girders) that are tied into the foundation by the top plate, and the transverse floors, also contribute to the stiffness of the foundation. However, the literature suggests that the over-all effectiveness of these members is relatively minor, even as common sense would suggest that these outlying members are going nowhere until the strongest link in the system, the central fully effective girders, start to deflect.

It is also realized that bending deflection as well as shear deflection occurs in the central fully effective girders. However, where the length of the girders is not less than approximately one-half the height of the girders, this effect too appears to be minor. In any case, the additional complication involved in calculating bending deflection (which involves moments of inertia of assumed configurations with assumed degrees of end fixity) is not warranted by the effect on the accuracy of the estimate.

As for the deflection due to inner-bottom rotation, the curves (Figure 2) reflect an assumed inner-bottom stiffness of 40 million, which appears to be reasonable for vessels of conventional inner-bottom structure. At any rate, the accuracy of the results of the foregoing procedure seems to justify and confirm the reasonableness of the assumed inner-bottom stiffness. The latter acts in series with the girder (shear) stiffness in resisting deflection, and these two values are therefore combined reciprocally.

The foregoing principles constitute the basis for the proposed procedure. It might be well to note that the longitudinal stiffness is independent of the number of girders, since the acting force (thrust) is assumed to divide equally between all the central fully effective girders. The corresponding deflections



Plan

Figure 2. Longitudinal Foundation Stiffness.

reflect this pre-proportioning of acting forces; the ratio of force to deflection (which is "the stiffness") being constant as a function of the geometry and physical properties of the materials involved. Of course, the value of the deflection, and hence the vibration amplitude, *is* a function of the number of girders, but this need not concern the marine engineer.

THE PROSPECT

It is to be hoped that the ideas presented herein may prove useful to all those concerned with thrust bearing foundations. For the machinery arrangement engineer it emphasizes the importance of allowing for longitudinal girders four to five times as long as they are high (from inner-bottom to top plate), in the area immediately below the thrust bearing, if a normally acceptable value of stiffness is to be achieved. The method also affords a quick means by which the hull designer can corroborate estimates of k_f submitted by design agents. It further provides an early index of practicable ranges of k_f in any given case for use in early design stage vibration analysis. Finally, the novel nature of the presentation permits the ready addition of check points for refining the curves as actual shaker test experience and results accumulate.

COMMANDER BERNARD M. KASSELL, USN

CHINESE WATERWAYS

THE AUTHOR

enlisted in the Navy in 1931, and has served continuously since that time. He attended Cornell University and Maryland University, obtaining his B.S. degree in Military Science from the latter institute. He has had a wide range of duty assignments, including tours as Engineer Officer and Repair Officer on various ships and tenders. He is currently stationed in Casablanca, Morocco as Commanding Officer, Military Sea Transport Service Office, Morocco.

In today's welter of headlines dealing with atomic bombs, Sputniks, the various missile families, and the crises, actual and impending, which torture relations between nations, it is, perhaps, understandable that the more mundane events of everyday life go unnoticed. For example, buried on an inside page of a great American daily newspaper not too long ago, was a report that Senator James E. Murray of Montana was concerned about the progress being made by the Soviet Union and by Red China in the vital area of river development. According to Senator Murray, Communist leaders have been putting more money and effort into river projects than into their more spectacular earth satellites and long-range missiles.

While the Senator's report was directed to the White House as part of an effort to "establish authoritatively that our country is rapidly losing out to the Communist leaders in the vital area of river development which is a prerequisite to economic, industrial, military and national strength," there is yet another aspect of the entire satellite water development plan which is overlooked. This aspect deals with the entire problem of Red trade. In both the Soviet Union and Red China inland waterways provide a ready route for both import and export traffic, in many regions of both countries, in fact, the only route. This trade, despite the total embargo maintained by the United States on trade with Red China, and despite the chipping away of other national embargo walls by sundry business interests, rose from $4.5 billion in 1955 to an annual rate of $6 billion in 1957. Thus, even without formal relaxation of previously imposed controls, these official figures reveal the extent to which the free world's trade with the Sino-Soviet bloc is increasing, a considerable portion of which trade, of course, must enter the country as well as leave, by water.

It is not the purpose of this discussion to enter into the pros and cons of east-west trade but, rather, to continue on from where Senator Murray left off and look into those aspects of his report dealing with the development which has taken place in China* not only along the inland routes, but along her coast as well, and in the field of shipbuilding for these routes.

A discussion of the pertinent facets of the Chinese water picture are relevant at this time because information on China's waterways is not yet as readily available as information on similar topics in the Soviet Union and because China, with its common border with the Soviet Union, the Amur River, has been in closer cooperation than ever before with that nation. This cooperation has been conclusively stated not only in formal treaty arrangements, but more circumspectly in the fact that available sailing reports suggest a virtual cessation in the transport by maritime means of raw and finished products to and from China from the bloc. Thus, rail shipments from the Soviet Union must eventually find their way via water to ultimate Chinese destinations.

Let us, therefore, proceed to our examination of the background of the development programs in China. China has a vast network of both large and small rivers, the total length of which is some

*For convenience Red China hereinafter will be referred to simply as "China."

192,000 miles.* Of this total, only 72,000 miles are suitable for navigation, yet, when the figure is compared with some 18,000 miles of railroad in an area covering almost 3,600,000 square miles of territory, the importance of the water sector is readily apparent. Happily for the Chinese, the rivers, unlike those in the Soviet Union, flow from west to east, thus permitting the tapping of the hinterlands. Included are the Yangtze, Huang Ho (Yellow), Hwai Ho, Pearl, Sungari, and Amur rivers. The Yangtze, one of the longest rivers in the world, is of major importance for the economy of the country, tapping as it does a basin covering one-fifth of the total territory of China, a basin occupied by over 250 million inhabitants. In its upper reaches the river flows through high mountains, but in its lower and middle reaches it is entirely suitable for navigation, despite difficulties with currents, rapids, and obstructions.

Second in importance is the basin of the Huang Ho, or Yellow River, which contains a population of 180 million persons. The Yellow River measures some 2,900 miles in length but is navigable for large ships for but a short distance in its lower reaches. Junks can, however, move well inland. By contrast, the basin of the Hwai Ho, in Mongolia, accommodates some 60 million persons and is suitable for powered craft over some 600 miles of its length, with junks used on the upper reaches. The famous Grand Canal, of limited use because of deterioration, begins near the city of Pekin and extends for some 1,100 miles southward to Hangchow.

In mid-1954 it was announced that regular night movement of ships on the section of the Yangtze River between Chungking and Ichang, for the first time in the history of navigation on that river, had begun. Beacons and buoys were of Soviet design, and Soviet specialists were active in assisting the Chinese in making the necessary improvements, assistance which has persisted until the present time and which has resulted in an interchange of visits by officials on both sides. Also in 1954 work was started to remove shoals along the Yangtze, as well as to widen and deepen the river at various points.

The first hydro-electric station in north China, at Kuan-t'ing (Kwangting), some 50 miles northwest of Pekin, was begun sometime previously and, with the coming into use of the station in 1955 or 1956, this station was to become part of the power network connecting Pekin, Tientsin and Tanshan. The reservoir built in connection with the station was started in 1951 and, upon completion, was to be listed as among the largest hydro-technical installations in China. In addition to its power use, the waters of the reservoir were to be used for navigation and irrigation purposes. To the east of Chungking, on the upper reaches of the Lungkiang (Lungtsza) River, a new hydro-electric station was to be built. This station, designed to hook up with other stations already in use, was to form a joint system for the transmission of electrical power for the needs of the entire Chungking region and was the work of Chinese engineers, assisted by Soviet specialists.

By 1957 the Pekin newspaper "Diligzhishi" was able to report that the generator capacity of the hydro-electric stations which had come into service since October 1949, the apparent commencement date of the expansion program, had reached very nearly 450,000 kilowatts, reputedly 38 times that of the capacity added by the previous government in twenty years. Five modern units were added to the Fyinman Hydro-electric Station, furnishing power to the principle industrial centers of northeast China such as Anshan, Fushan, Tszilin and Chanchun. The station's reservoir was to assist in keeping 370,000 acres of arable land from flooding during certain seasons of the year. Kwangting, previously mentioned, furnishing power for Pekin, has an installation of 30,000 kilowatts, while the largest hydro-electric station in southwestern China, that of Shitszyitan, rated as a 48,000 kilowatt installation, began power delivery in October 1956. Other stations were built near Urumchi and also in Lkhasye. By mid-1957 a station was under construction on the Lyutsikhe River near the city of Guanchzhou and on the Shanyutszyan River as well. The latter is to provide power for the nonferrous metals mining enterprises in the south of the province of Tszyansi. Plans were also afoot for the construction of five large stations on the Yellow River in the provinces of Chzhetszyan, Yunnan and Syichuan, the total power of which is stated to be 3,200,000 kilowatts. The ultimate aim is an integrated power system for the entire country.

Thus, the expanding program of electrical development results in improving navigation on many sections of various rivers with the ultimate result that cargo moves more readily, flooding is reduced and, an important factor in itself, the burden on the railroads is reduced. In passing, it may be noted that since the Communists took over in China, some 1,200 miles of railroad have been restored and built in northwest China alone. Plans continue to tie the rail systems of the Soviet Union and China together, adding yet another link in the chains which bind the two nations.

On the rivers most of the cargo moves in the ubiquitous junk, at least 30,000 of which, totaling some 447,000 metric tons of carrying capacity, are in use on the Pearl River alone. The larger junks can carry as much as 200 tons, the smaller ones three tons. Propelled by oars, sail, or both, the junk has been, and is, the workhorse of the Chinese rivers. At the same time, modern practice appears to be trending towards the use of powerful tugs towing caravans of from 30 to 40 junks, particularly upstream.

Inland transportation, as well as maritime and automobile transport, is under the Ministry for Communications. State steamship companies are subor-

*By contrast, navigable waterways in the United States total 29,000 miles, which in 1957 accounted for 123 billion ton miles. For the Soviet Union, with some 80,000 miles of inland routes operational, the planned figure for 1958 is on the order of 47 billion ton miles.

dinated to this Ministry and are engaged primarily with transit cargoes. Local transportation is carried on by steamship lines which are subordinated to provincial committees established for this purpose. The state companies control routes, fleets, ports, ship repair enterprises, security organizations within individual companies, as well as such technical schools as exist.

The largest company is that operating on the Yangtze and, organizationally, is patterned after the Soviet Union's Volga Combined Steamship Line (a grouping of three subordinate steamship lines operating within set boundaries on the Volga River) and controls three regional organizations: Chungking, Wuhan (the triple city complex of Hankow) and Shanghai. Some idea of the size of the company is revealed by the fact that forces afloat number in excess of 20,000 men, while cargo handlers number some 15,000. In all, including administrative and other personnel, the company employs in the neighborhood of 54,000 persons.

The influence of the Soviet Union in China's organization and use of her water resources is quite apparent and is of direct impact where the Amur River is concerned. In the spring of 1957 Z. A. Shashkov, Minister for the River Fleet of the Russian Socialist Federated Soviet Republic, together with a delegation of Soviet river specialists, visited China and apparently laid the groundwork for the "Agreement Concerning Navigation and Trade on the Amur, Sungari, Ussuri, Chernyiy Irtyish, Ili, and Sungucha Rivers and Lake Khanko" which was signed by the two nations in December 1957. The Amur, subject to flooding and low water in turn, will be the object of joint study on the part of the treaty signatories, in an effort to improve conditions on the boundary river. At the same time, Chzhu Li-Chzhi, Deputy Minister for Communications in China, at the time of the signing of the agreement, furnished an insight into the future relations between the two nations by stating that the Soviet Union will use cargo motorships, tanker barges and tugs for carrying cargo on the waters in question while China will confine her usage to the presently available barges and small tugs. The Deputy Minister indicated that the Chinese fleet was to be increased in the near future, in line with construction programs which will be discussed later on. The Chinese delegates to the Soviet Union, where the agreement was signed, were given the "red carpet" treatment and were shown various installations in the Moscow area, as well as out of bounds areas such as Gorkiy, on the Volga River.

In China, as might be expected, the Yangtze River basin has received the major share of the attention given to inland resources, since it occupies first place in the inland water picture. Between 1953 and 1956 conditions were "improved on 45 sections of the river" in order to do away with the station vessels used to assist caravans in passing particularly dangerous points. Withal, the Yangtze remains a dangerous piece of water. Observations made on various sections have revealed an incredibly swift 15-20 miles per hour current, as well as places where water levels rise and fall as much as 100 feet. At such places special "drag" stations have been set up to hold back downstream caravans and assist those bound upstream. At points such as these downstream passage is possible only during daylight hours. Below Ichang, however, as has been pointed out, ships can move at any time of the day or night, additional lights, markers and buoys having been installed to assist in such use.

All this work, the improvements and the building program to be discussed, is designed to support a river fleet which, according to available figures, occupies second place in China's cargo turnover. Rail, of course, occupies first place but not, for example, in the same degree that it does in the Soviet Union. In 1956 the relationship between the various modes of transportation in China was about as follows:

Type of Transport	Metric Tons Share in Percentage	Ton-Kilometers Share in Percentage
Railroad	33.0	78.7
River	14.6	12.1
of which		
In ships	4.7	8.5
In junks	9.9	3.6
Cabotage	1.5	5.7
Automobile and truck	10.7	2.3
Wagon and cart	40.2	1.2
Total	100.0	100.0

For river transportation these percentages represent an increase in tons carried of two and one-half times that of 1949, during which period (1949-1956) the length of the routes serviced increased 30 percent. The commodities carried in 1956, in percentage of the total volume for the year, have been broken down as follows:

Type of Cargo	Metric tons	Ton-Kilometers
Grain	26.0	37.6
Mineral-building Materials	24.7	9.5
Coal	9.0	9.6
Oil	0.7	1.8
Timber	3.9	5.0
Ore and ferrous metals	1.7	4.7
Salt	3.9	4.4
Cotton	1.0	2.1
Miscellaneous	29.1	25.3
Total	100.0	100.0

The Yangtze basin, quite naturally, accounted for the major share of cargo, handling 75 percent of all cargo hauled, and accounting for 85 percent of the ton-kilometer performance figure. So it comes as no surprise to find that the major portion of the river fleet operates on the Yangtze and its tributaries. Between 1949 and 1956, in order to meet the needs generated in the basin, steam tugs rated at 150, 300, and from 2,000 to 2,400 horsepower, as well as steel barges capable of carrying 700, 1,000 and 2,000 metric

tons, were built and supplied to the Yangtze. One such vessel is the motorship *Tyan-Sya,* built in Shanghai in 1955 to Chinese design. The vessel is rated at 1,800-hp, carries 356 passengers and 200 tons of cargo, and can make about 8 knots.

At the same time, despite the problems which have arisen along the China coast, the claim is advanced by the Chinese that use of coastal waters is retained and in fact, trade moving via these waters has been expanded. China's coastline extends for some 7,000 miles, making the need for some means of carriage by water virtually mandatory. In addition, the ports along the coast are the sole means for communicating with the rest of the world, disregarding, of course, the long and tenuous rail connection via the Soviet Union to western Europe. According to Chinese sources ships of 21 nations made 1,725 calls in Chinese ports in 1956, an increase over 1955 of more than one-third. 682 calls were made by British-flag vessels, 535 by Japanese. Shanghai is said to have exported goods to 68 different nations. According to the 1957 plan, the total cargo turnover figure for maritime cabotage trade was to total 5.8 billion ton-kilometers, a considerable increase over a comparable 1950 figure of 0.8 billion. The total maritime tonnage available to China, as of February 1958, was 300,000 tons. By 1962 this figure is planned for increase to 600,000 tons of capacity. While the Chinese claim removal of three-fourths of available tonnage to Formosa in 1949, with damage to the remainder, as well as damage to ship repair facilities, landings, warehousing and other shore installations, no real claim is made to destruction of vital ports, so that as soon as bottoms were available cargo was able to move. Too, the Chinese claim that all Chinese cabotage transport is accomplished by Chinese vessels is untrue, refuted by Soviet reports of the assignment of Soviet merchant ships to cabotage trade between Chinese ports during those seasons of the year when ice precludes use of shipping in the northern regions of the Far East. The usual practice during the late fall and winter months, extending into the spring, is for the Far Eastern Steamship Company of the Soviet Union to assign certain of its vessels to the Chinese coastal trade, in which they carry such cargoes as coal, ore and the like. The exact arrangements have never been clear, but presumably the agreement is on a charter basis.

Nevertheless, there appears to be considerable validity to the Chinese claim that between 1950 and 1957 the tonnage of river ships, and of merchant ships engaged in the cabotage trade, has doubled. And there is little reason to doubt the claim that the cargo turnover of the six largest ports in China (Canton, Tsingtao, Shanghai, Tientsin, Chinwangtao, Dalnyiy) has increased 48 percent between 1955 and 1957, to a record level. As has been noted, this increase has stemmed, from among other things, the increased tonnage which has come into use as a result of the shipbuilding program.

As early as March 1954 it was announced that shipbuilders in the Tszinnan (Chin-nan?) Shipyard had launched the 900-ton displacement passenger steamer *Minchzhun.* Designed for the shallow section of the Yangtze between Shanghai and Chungking, this was the first large steamship built for use after the Communists had taken over, and the first, it is said, in China's history to be built by Chinese engineers and workmen from Chinese materials.

By early 1957 it was announced that China was building eight classes of transport vessels, six of them self-propelled. Included in the building program was a single-screw cargo-passenger type for use along the coast which was rated at 700-tons deadweight. The main engine was a 4-cylinder, vertical steam engine, triple expansion, developing 1,500-horsepower, and capable of driving the vessel at 11.5 knots. Too, a 120-ton displacement motorship was under construction for use in the inter-island trade along the China coast. An ocean-going tug, displacing 620-tons on a 44.45-meter long hull with a 9-meter beam and drawing 3.36-meters, was to be equipped with salvage and rescue equipment, including pumps capable of assisting flooded or damaged vessels. Equipped with two 600-horsepower diesel engines, the tug was to have a range of 16 days at sea.

It is claimed that, in addition to the new building, over 100 ships sunk during the fighting with the Nationalist forces have been raised. Many of these, some in the 4,000 to 5,000 tons deadweight class, have been repaired and returned to service.

For the rivers, the building program includes a series of steam tugs in the 2,000 to 2,400 horsepower class. The hulls of these tugs conform to the design of seagoing types which have, in the past, seen extensive use on the Yangtze River. Barges under construction have the usual spoon-shaped bow and stern familiar to Chinese rivers, and are now of partly welded construction. They are built in both hold and flat-type classes. Deck barges are occasionally equipped with tanks for carrying liquid fuels. This idea appears to stem from the fact that in actual practice, on the Yangtze at least, dry cargoes move downstream, liquid cargoes upstream.

Passengers are accommodated on Chinese rivers on large cargo-passenger types rated variously at 2,400-horsepower and, by newer standards, 3,200-horsepower. A 700-ton deadweight, 1,540-ton displacement diesel driven vessel of this latter horsepower was among the types under construction in early 1957. Drawing 2.4-meters at full load, the vessel was equipped with two high-speed diesels and was capable of making 13.5-knots. A dry-cargo type under construction, *Dachzhun,* is 1,800-tons deadweight, making 13.5-knots at a draft of 3.6 meters. Propulsion is provided by two triple-expansion steam engines of 1,800-ihp each, furnished with steam from two coal fired boilers which are mechanically fed. A second type, of 1,000-tons deadweight, makes 12.5-knots. This class, *Zhenmin,* was designed

for use on shallow routes and was equipped with a 1,000-ihp steam engine. A 100-ton capacity flat barge was under construction for carrying coal, paper, crated fish and other cargoes, while a tank barge was being built which was rated at 3,700-tons capacity. Displacing 5,200-tons, the barge was 101.9-meters long, 16.8-meters in beam and would draw 4-meters loaded.

In mid-December 1957, it was announced that the Dalnyiy Shipyard, at one time under Soviet control, had launched a 4,500-ton capacity tanker, the first large vessel built by the enterprise. This yard had been a repair base for Soviet merchant vessels in the Far East and had, in addition, been building small cutters, resembling river trams and seating 70 passengers, four of which were known to have been turned over to the Soviet Union in 1956 for use in the port of Vladivostok. On the heels of this announcement came another concerning the construction of the first two icebreakers completed in China. In January 1958, they were successfully tested in the lower reaches of the Yellow River. While the building yard was not mentioned, it is presumed to be Dalnyiy, in view of the proximity of that yard to the test area. Too, in mid-May 1957, Dalnyiy was the launching site for a cargo vessel displacing 8,700 tons, the first vessel of this size to be launched in China. The plans, drawn by Chinese engineers, call for an all-welded hull. The vessel is for use between ports in China and those of southeast Asia. Such use will provide Chinese Communists with a controlled means for contacting members of the overseas Chinese communities, with results yet to be definitely established. Dalnyiy is also scheduled to begin the construction, in 1958, of an ocean-going steamship displacing 10,000 tons.

In fact, the Chinese news agency has stated that in 1958, the fleets, river and maritime, of China will be increased by 380 vessels, including two ocean-going ships of the displacement noted above. Initially this seems somewhat beyond present capacities of available yards, but it is known that a new shipyard is under construction in Guanchzhou, while the ship repair yard in Shanghai is to be expanded and a new ship repair yard is to be built in Wu-han.

An assist for maritime transportation comes from articles which appear in a special monthly publication, "Shui Yun" (Water Transportation), published in Pekin. The periodical acquaints its readers with new techniques in the field of water transportation and serves as a medium for dealing with problems connected with both river and maritime transport. The journal regularly publishes articles by Soviet specialists in the field, as well as articles by Japanese and other foreign writers.

In addition to an expanding fleet, programs connected with port expansion are also underway. In 1956 the construction of a new port in Fort Bayard was completed. Today the port is stated as having moorings equipped with eight portal and one gantry cranes, all of which are electrically operated. The moorings can handle two 10,000-ton displacement vessels simultaneously. An additional pier, under construction early in 1958, to the north of the present pier, when completed will enable the port to handle an additional 5,000-ton displacement vessel and two vessels displacing 3,000-tons each. An oil pier was also under construction at this same time and, when completed, will be able to handle tankers displacing up to 25,000-tons. Present Soviet tankers, it may be recalled, displace 16,000-tons, but one tanker in the 25,000-ton class is presently under construction in the Soviet Union. When the first stage of the development work is completed the port's capacity will be 1,600,000 tons per year, and after the second stage work is done, capacity will be increased to 4,300,000 tons per year. Various other ports, river and sea, including Shanghai and Chungking, are slated for expansion while primary work in an unnamed port on the west coast of Hainan Island is scheduled for completion this year.

Silting in the ports, however, requires a considerable outlay in both manpower and money, in order to maintain them operable. The port of Singan, at the mouth of the Hwai Ho, for example, silts up at the rate of 4,820,000 cubic meters per year and a constant dredging project is needed in order to operate the port at its normally anticipated capacity. Efforts are afoot to remedy the situation by reducing the width of the exit from the port from its present 700-meter width so that the narrower channel thus formed will result in increased velocity of the downstream current, with the silt to be carried out to sea rather than being deposited within the confines of the port.

Let us now look into the matter of the methods in use in the field of water transportation in an effort to ascertain the relative efficiency of the Chinese fleets and their operations. Information on the subject is far from complete, but what information is available makes for interesting reading. Representative is the Pearl River basin, in southern China, where the tug fleet is being increased as a result of the building program going on in Canton, where 200-hp steam tugs are under construction. The basin contains 549 self-propelled vessels, of which 300 are propelled by automobile-type engines using generated gas for fuel, 55 are diesel propelled, 58 are ignition-chamber type, and the remainder are steam propelled, the most powerful of which are rated at 240-hp. The scarcity of liquid fuel in China is well known and, when available, costs ten times as much as coal. Hence, the strong leaning towards coal burning steam propelled vessels. Interestingly enough, Chinese engineers seem to have developed a method of burning coal which is superior to anything yet developed in the Soviet Union, a method which has been adopted on coal burning ships in the latter country. In turn, the Soviet Union has recommended that the Chinese study the possibility of replacing

the 2,000-hp tugs now in use and planned for the Yangtze with self-propelled cargo ships. The Chinese have also been advised to use gas-generating plants as well as internal combustion engines operating on the liquid gas principle. Technical and economic indices on presently operating steamships are subject to improvement by modernizing certain operating methods, by the use of increased steam pressures and temperatures, and by the installation of modern equipment, such as exhaust turbines.

As has been noted, some 30,000 junks are in use in Pearl River basin, the utilization of which by the some 160,000 river workers, is poor. On the Yangtze, by contrast, the average speed of tows, in 1955, was sufficient to enable the tows to make 230-kilometers per day, the best performance figure in the country. Cargo vessels made 215-kilometers per day, but the loading per horsepower, stated as 3.06-tons, was such as to yield 393-ton kilometers per horsepower per day for the tugs, as opposed to a similar figure of but 62-ton kilometers per ton of capacity per day for the cargo types. The Soviet Union, using its highest producer, the Volga Tanker Steamship Line, could yield a figure of but 159-kilometers per day. However, the Soviet tows, of purely liquid cargoes, produced 900-ton kilometers per horsepower per day, or very nearly two and one-half times the Chinese figure. And, surprisingly, Chinese ultilization figures indicate underway time of 50 percent as opposed to a figure of 35 percent for the Soviet Union. Should the Chinese see fit to change their methods and use the pushing system, assuming this system is suitable for Chinese waterways, the utilization factor may be further increased.

Repairs are carried out on a schedule somewhat as follows. Capital repair is done somewhere between 9 and 12 years after the ship is placed in service, assuming a new vessel, or within that time period after the most recent major overhaul. This type of repair takes from three to four months and from 50 to 70 percent of the crew is kept with the vessel. Middle repairs, so-called, are carried out every four years, usually lasting from 70 to 80 days, with full crew retained. Current repairs include annual docking, which is done usually during the winter lay-up period and is normally scheduled for from 50 to 60 days. However, these time periods are optimum, and if recorded results are any indication, seldom fit the pattern described.

Port handling work is becoming increasingly mechanized; facilities are improving and efficiency is increasing. Specifically, the river port of Chungking was expected, in 1957, to increase its cargo handle to six times that of 1952, or to about 3.7 million tons (excluding cargo handled by the junk fleet). In the so-called Second Five-Year Plan, the port is expected to increase its handle to 5 million tons per year. It is reported that the port has a special landing to handle cargo requiring mixed rail-water transportation, with five rail lines having been extended into the port area. An interesting sidelight is the fact that, since navigation above Chungking is possible only during daylight hours, the port works cargo mostly in the evening and at night. On the other hand, Hankow, also on the Yangtze, compares favorably with the Volga port of Gorkiy in the Soviet Union. Hankow, with landings on both sides of the river, handles in excess of 6 million tons of cargo per year, and is equipped with marine railways, transporters, floating cranes and other equipment. A transshipment point of major importance, Hankow serves all of central China. The extreme ranges in the river's water level, however, cause difficulties for the port, a problem not uncommon in all river ports. A possible remedy is suggested in the equipping of the ports with floating, rather than fixed, landings, as well as by mounting cargo handling equipment on floats, as is the case in Shanghai, where the daily tide differential is as much as 13 feet.

Finally, and of perhaps overriding importance, is the fact that a continuing weakness in the whole of the water transportation system, river and maritime, is the lack of trained personnel. While two operating training schools provide personnel, as does a port workers' school in Hankow, the weakness persists, hampering improvement in the field. It is in the field of training, perhaps, that the most fertile area for Soviet penetration exists, a field which Soviet specialists will be able to plow and plant to their own needs in the guise of "friendly cooperation."

COMMANDER RANDOLPH M. ELDREDGE, USNR

THE FUTURE AND OUR RESERVE FLEETS

THE AUTHOR

a graduate of Rensselaer Polytechnic Institute—1937. He served in the South Pacific and later with the Service Forces 7th Fleet during World War II and Service Division 31 in Japan during the Korean action; was the Material Officer of the Charleston, South Carolina Group, Atlantic Reserve Fleet for three years before his present assignment as the Resident Supervisor of Shipbuilding at Cleveland, Ohio.

THE Chief of Naval Operations, in testimony to the Congress, has pointed out that our reserve fleets are growing progressively less valuable due to obsolescence. Why then do we continue to maintain ships in reserve? Is a complete revaluation of this policy in order now that we have entered the guided missile age? Can we afford to spend any money on reserve ships under the present conditions of skyrocketing weaponry costs?

Commander R. E. Williams in his prize winning 1958 U.S. Naval Institute essay "Task for Today—Security through Seapower" points out that "on the present federal reserve base, our military establishment is simply insolvent." His very logical thesis is that our best bet for avoiding bankruptcy and insuring survival is the further development of sea-based retaliatory power. This deemphasis of fixed land bases will largely negate the advantage traditionally conceded the enemy, the opportunity to strike the first blow.

Sea power is comprised of both naval and merchant vessels. Each complements the other. Loss of the reserve component of either force appreciably lessens the immediate usefulness of the other. The importance which the Joint Chiefs of Staff attach to our merchant navy is indicated by the following quote from a letter from the Chairman of the Joint Chief of Staff to Senator J. M. Butler, as reported in "Marine Engineering/Log," December 1957:

> "It seems incredible to me than anyone could argue seriously or with justification that new concepts of warfare obviate the necessity of further fostering a merchant navy. I assure you that such views are not held by the Joint Chiefs of Staff . . . If the catastrophe of a general war should be forced upon us by the necessity of retaliation against a surprise attack, the merchant marine, after the initial period of devastating nuclear exchange, would play a most vital role. Indeed, it might very well be the one source of strength of the Free World which would pluck victory from chaos."

Our reserve fleets, both naval and merchant, form excellent missile targets not susceptible to meaningful dispersal in the missile age. Our present concepts of activation visualize a basic activation period of 30 days for naval vessels, albeit most Korean activations required more time, and somewhat longer times for the merchant vessels.

Assuming the validity of the above premises it appears that our reserve of vessels, both naval and merchant, have little prospect of surviving the devastating nuclear exchange which, presumably, would be the first act of any future general war. However, we may assume that some of the enemy's missiles will misfire or fail to hit their target for various and sundry reasons. Some of our reserve vessels will then almost certainly survive the first few hours. If these vessels can then be activated on a crash basis and moved out to sea in a matter of hours after catastrophe strike, their chance for ultimate survival is good. If left in the berthing areas for several days or weeks they would almost certainly receive disabling

damage or become too contaminated radiologically to be of further usefulness.

It appears that, unless we can significantly reduce the time required to activate vessels, we should cease to consider our reserve fleets as potential wartime assets and should discontinue the expenditure of funds thereon.

The purpose of this article is to propose the "Single Package" concept of vessel inactivation which has the following potential advantages:

(a) It makes possible a significant reduction in activation time by reducing the steps required to activate. This should make the 24 hour activation feasible.
(b) It completely eliminates deterioration of normally exposed topside components. This eliminates delay at activation and significantly reduces maintenance while in reserve.
(c) It provides complete protection against radioactive fallout.
(d) It can reduce the real cost of inactivating a vessel.

Some, who activated ships during the Korean episode, will say that talk of a 24 hour activation is fantastic and even impossible. It most certainly will require planning and advance preparation of a high order as well as radical changes in the procedures currently in effect.

Let us consider a typical steam propelled ship fully active. Suppose we bring it alongside a pier, secure the fires in the boilers, march the crew off and close the doors and hatches. That ship, fully equipped but with a cold plant, can most certainly be activated and gotten underway by a trained crew in a matter of hours. However, if allowed to remain in that condition, the ship would soon deteriorate to the point where it could not be activated without extensive repairs. In other words, certain preservative measures are necessary for long term inactive stowage. We must develop preservative measures amenable to being thrown off in a matter of hours to again place the ship in the condition of the ship which we considered above.

Now let us consider what we do to a ship in preserving it which requires 30 days or more to undo at activation. These procedures are completely covered in Chapter 9, Bureau of Ships Manual, but the major steps are outlined briefly in the following paragraphs.

First of all we drain and clean the boilers and place all the steam system under preservation by circulating dehumidified air through it. There is no great problem here in removing the D/H machinery, reassembling the piping, filling the boilers with water and lighting off, assuming the boilers were properly inactivated and were clean, dry and in good condition at inactivation. Fuel oil stays aboard.

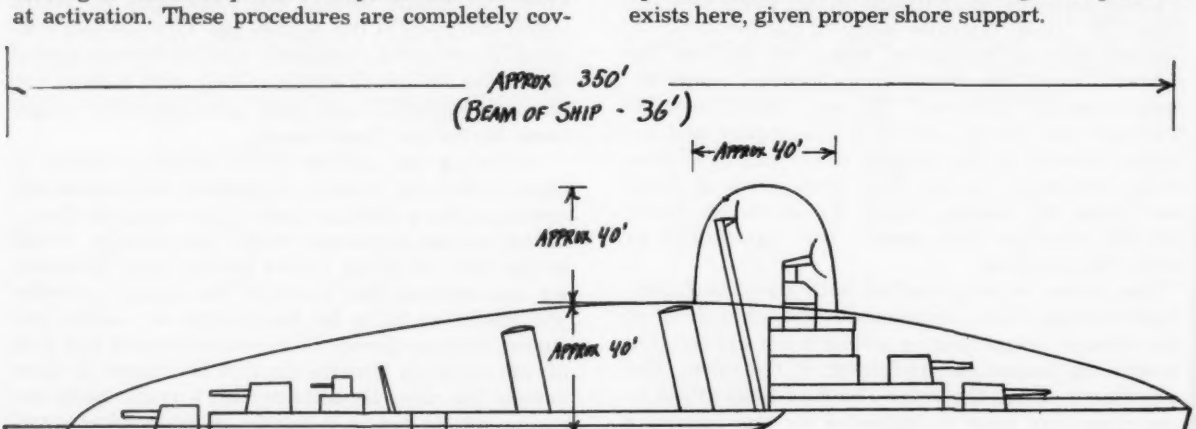
The shafting bearings have to be protected to exclude marine growth which may score the bearings after activation. This is done by rubber boots. These present no problem as a diver can cut them off, or their presence can be ignored and jacking of the shafts will rip them off.

In the case of the machinery we apply preservation compounds to replace the lube oil. While these preservatives are normally washed out and removed at activation this could well be eliminated on a "calculated risk" basis and we would have no delay here as lube oil stays aboard.

Our typical ship is an alternating current ship. There is essentially no inactivation required for this type of electrical equipment assuming it to be clean and in good condition. Preservation is accomplished by dry air throughout the ship. No problem here.

Now we come to the piping systems. To keep the interior of the ship dry for preservation purposes we must eliminate all leakage into the ship. Sea valves will do this but under long term inactive stowage the sea chests accumulate marine growth. Accordingly we must blank all sea chests. While it takes time to remove these blanks a sufficient number of skilled men can do so with remarkable rapidity. So we have no real problem here.

We have had to remove all foodstuff and perishables from the ship. Replacement of these is merely a matter of planning and organization. The actual operation need not be time consuming so no problem exists here, given proper shore support.



Single Package Installation on a typical 421 Class Destroyer

Official U.S. Navy Photo

SAN DIEGO GROUP PACIFIC RESERVE FLEET. Candidates for "Single Package" preservation.

Now we come to the real problem area, which is making the ship air tight for dehumidification purposes, and in preserving the myriad of topside mechanisms, components, electrical fixtures and structures. These are all very susceptible to deterioration from the weather, if not frequently exercised and preserved. So what do we do? We remove all readily removable components, tag them and stow them below. These run into the hundreds on the average ship. Some are always missing at activation. Unless properly organized at inactivation (and it frequently isn't due to the short timer attitude of the personnel involved) the reinstallation of this gear can be a staggering task at activation. It can involve such components as boat winches, radar antenna, vent blowers, vent hoods, smaller ordnance gear, searchlights, ready service lockers, depth charge projectors, etc., ad infinitum. Additionally, we install blanks over all vent openings, which run into the hundreds. We also install complete metal enclosures over gear such as guns and winches too large to strike below. All these must be removed and some of the removals require crane service.

In spite of all this topside preparation we find much deterioration after a number of years. Life line stanchions rust off. Davit sockets deteriorate. Electrical junction boxes fill with water. Watertight doors rust out, decks and bulkheads corrode through. Anchor windlasses and boat davits freeze up. All these conditions must be corrected at activation when we have no time.

We find that dynamic dehumidification keeps the interior of our ships in excellent condition. The topsides are the problem. Why not package the entire topside area of the ship from the tip of the mast to the weather deck and place the entire area under dynamic dehumidification? Then we would eliminate the necessity for striking anything below, for blanking anything (other than sea valves) and at the same time we would eliminate all topside deterioration and maintenance. We would also protect the vulnerable topside areas from contamination by radio-

Official U.S. Navy Photo

RESERVE MERCHANT VESSELS MOORED IN THE JAMES RIVER. More candidates for "Single Package" preservation.

active fallout. This feature alone could be of incalculable value in time of emergency and could easily mean the difference between using and not using the ship.

This proposal is fine as far as it goes, but how do we go about achieving these desirable objectives at any cost, let alone at a reasonable cost?

The rubberized nylon air-inflated portable warehouse is a recent and well publicized device to cover a large area in a hurry in a semipermanent manner. This type of construction could be readily adapted to installation on a ship and should be durable enough for several years use. The D/H machine itself would provide sufficient air pressure to inflate the enclosure. Provision of an air-tight joint between the hull and the envelope should present no insolvable problems and the package would be virtually air and vapor tight, a condition favorable to the maintenance of low relative humidity. As with all new concepts, some bugs would have to be worked out as a result of operating experience.

For long time stowage of vessels the air-inflated enclosure could be installed temporarily and used as a form on which to build up a fiber glass reinforced plastic enclosure over the hull. Build-up would be by spraying alternate layers of glass mat and resin onto the rubberized nylon, which would be removed after curing of the plastic. This enclosure would be self-supporting, have a virtually unlimited life span, and be adaptable for partial opening to permit alterations and repairs to the vessel.

It is believed that developmental work along the above lines can result in a practical enclosure which will reduce reserve fleet maintenance and inactivation costs and make possible the 24 hour activation which we must have if our reserve fleet vessels are to make a contribution to the national survival in the event of World War III.

It goes without saying that ships, preserved by the "Single Package Concept," must be overhauled and

placed in good operating condition prior to layup. The whole purpose of the fast activation is defeated if, after activation, we have to overhaul the ship to make it operable.

The rapid and relatively inexpensive activations and inactivations made possible by the single package concept open up the possibility of frequent interchanges of ships between the active and inactive fleets. This would give the crews training in ship activation, permit an accurate evaluation of the condition of ships long in reserve, and facilitate modernization of inactive ships after activation and shakedown at sea. In the present situation, with time collapsing, it is absolutely essential that both active and reserve personnel receive actual on the job training in ship activation before the onset of hostilities. This will ensure that our reserve fleets constitute an actual deterent to aggression rather than a nebulous addition to our active fleet strength.

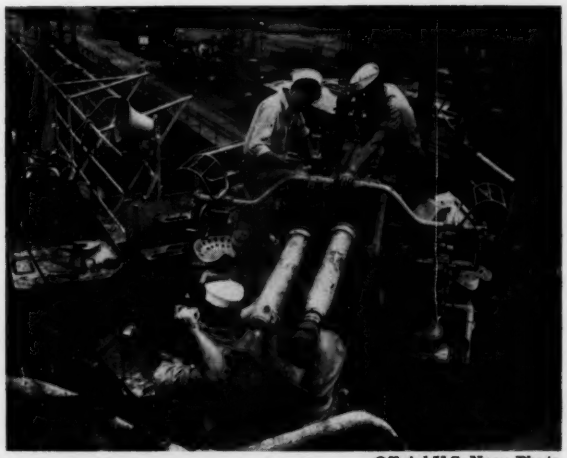
The present mobilization planning concepts, which call for reporting of the ship's crew within 10 days after D day, are unsuited to conditions in the guided missile age. Reserve fleet personnel can throw off the "single package envelope," and run water into the boilers. That is to no avail unless a trained crew is immediately on hand to load the groceries and ammunition, fire the boilers and get underway.

Any officer with experience knows that you are not going to be able to operate a ship, even one already fully active, by simply marching a number of bodies, numerically equal to the ship's complement, on board and telling them to "get it underway." A ship's crew is a team which must be trained as such and which, collectively, must possess considerable experience.

Where are we going to get these trained crews in an emergency on a 24 hour basis? We have a large reserve organization in being. However, the reserve, as the author understands it, is not set up to provide trained crews but rather to provide trained bodies who can be quickly integrated into crews. The mechanics of the situation are such that placement of trained reserve crews on active duty within 24 hours is improbable. This means that, if we are going to activate our ships within 24 hours, we must have another source of crews initially.

Official U.S. Navy Photo

CLUTTERED TOPSIDES. This view shows some of the many and varied topside appurtenances subject to deterioration during a vessel's stay in the Reserve Fleet. The "Single Package" concept substitutes one enclosure for many.



Official U.S. Navy Photo

ACTIVATION AND/OR INACTIVATION. The "Single Package" concept permits work of this nature to be done BEFORE, rather than DURING activation.

The only place to get trained crews in a hurry is from the active fleet. We must split cadres from the crews of active ships and utilize them to get the inactive vessels underway. These personnel can then be augmented by the reservists as soon as they can be called to active duty. Operating the ships shorthanded, during the initial onslaught, will be hard on the personnel involved but it could make a significant contribution to the national survival in the event it became necessary.

One important advantage of the single package concept, not touched on above, is that it will make possible a new approach to reserve training. It will, to a limited extent, make possible the provision of all reservist crews trained as a unit, on the actual ship to which they will be ordered on D day. If desired this could even be carried to the point of assigning the men to the bunks they would use in the event of mobilization.

The single package concept makes this possible since the ship itself is much more accessible than the normal inactive ship. While entrance to the topside envelope itself is closely restricted, once inside the envelope the ship is wide open. All doors and hatches are open and all components are fully assembled.

Utilizing shore power, radars can be operated, guns exercised, ventilation and lighting is fully operable and everything normally available on the ship is on hand except water, steam and perishables. Reservists on annual training duty can run through

Official U.S. Navy Photo

445 CLASS DESTROYER UNDERWAY. This is the way one of our typical vessels would appear after removal of the "Single Package" preservation.

drills right on the ship to which they will be assigned. They can light off and operate all electrically operated components and systems thus familiarizing themselves with the vessel. Likewise they can examine and become familiar with the instruction books, plans, allowance lists and other documents carried on board and needed to operate the ship. They can advise the Reserve Group Commander as to any deficiencies on the vessel which will hinder activation and request him to take corrective action.

In the case of reserve units located in close proximity to a reserve fleet berthing area the prospective crews could become even more intimately acquainted with "their ship." However, the number of units so located is bound to be relatively small and the composition of the average unit does not correspond to that of a ship's crew in most cases. Thus the training of reservists as a crew on their own ship would be confined primarily to periods of annual training duty.

What about "Brush fires," those limited skirmishes where speed is of the essence in extinguishing the blaze before it becomes a conflagration? The Crash Activation made feasible by the "Single Package Concept" is a natural here as it means that we need not retain in the active fleet as many vessels as otherwise necessary once we have the means at hand to expand our active fleet by as much as 100 per cent in a matter of days or hours. The savings possible in this area over a decade are of tremendous import in this era of chronic fund deficiencies.

To summarize the situation we may assume that, in the event of World War III, the traditional American policy of conceding the enemy the first blow will obtain. Since our survival will be at stake we must assume that this first blow will be as staggering as the enemy can make it. Such of our missiles as survive will return the enemy's first salvo in kind. Following the initial round each side will then pick itself up off the deck and fight a lower order war with such facilities, weapons and manpower as are available. The victor, if there can be one, will be he who survives with the most. Our initial task then will be to salvage as many of the reserve ships as possible and get them mobile and out to sea until we are in a position to use them. Speed is of the essence as the enemy will, if he is able, be around in short order to clean up any inviting targets missed on the initial blow and secondary targets worthy of attention. Concentrated groupings of ships form an excellent missile target. Accordingly we should:

(a) Dispose of all reserve fleet vessels for which no clear cut mission exists.
(b) Develop and perfect the single package preservation concept and the 24 hour activation.
(c) Overhaul, modernize and place in "Single Package" stowage all reserve fleet vessels retained or inactivated in the future.
(d) Reorient the reserve training program to train crews rather than bodies. Earmark these crews to specific vessels.
(e) Plan on manning the crash-activated ships initially with cadres from active fleet vessels.
(f) Place the single package concept into service on our reserve merchant fleet.
(g) Establish a reserve type organization to crash-activate a significant proportion of our inactive merchant fleet.

NEW ENGINEERING METALS

ACKNOWLEDGEMENT

This article appeared in the August 1958 issue of "Mechanical Engineering." The authors are J. P. Denny and L. F. Kendall, Jr., General Electric Company, Schenectady, New York.

FACED WITH the need for materials of unprecedented strength, heat resistance, and corrosion resistance, engineers today are employing metals formerly dismissed as wholly impractical.

Seven such metals are: zirconium and hafnium (periodic table group IV B); vanadium, columbium, and tantalum (group V B); chromium (group VI B); and rhenium (group VII B). All are available in at least developmental quantities. Considerable data are available on some, while limited information has been obtained on others (Tables 1 and 2).

ZIRCONIUM

Zirconium has come of age. The capacity for production of this metal in the United States has increased nearly 3000-fold, from a few thousand pounds in 1947 to 6,000,000 lb. per year in 1958. The impetus for this rapid advance has come primarily from this country's atomic-reactor program which will consume 3,200,000 lb. per year. However, the availability of zirconium in quantity will permit designers to exploit its unusual properties in a variety of applications.

"Commercial grade zirconium" is actually an alloy since it contains between 1.0 to 2.5 per cent hafnium, depending on the composition of the ore. It is perfectly satisfactory for nearly every application, but the nuclear properties of hafnium necessitate its removal if the zirconium is to be used in atomic reactors. The separation is effected during the chemical processing to yield "reactor-grade zirconium" containing less than 0.01 per cent hafnium.

For reactor applications, minor amounts of tin, iron, nickel, and chromium are usually added to pure zirconium to produce the alloys, zircaloy-2 and 3. These additions enhance the corrosion resistance in very high-temperature water and simultaneously raise the strength of the metal. Both grades of zirconium and the zirconium-tin alloys are available in standard shapes and forms such as—plate, sheet, rod, wire, tube, and castings.

The Practical Price

The price of zirconium recently has been substantially reduced, reflecting the competitive nature of this young business. In 1000-lb. lots, commercial-grade sponge is now priced at $5 per lb., while reactor-grade sponge is quoted at $7.50 per lb. These prices are only one third those of four years ago.

The outstanding property of zirconium is its corrosion resistance. Media in which it is especially useful include hydrochloric, nitric, sulfuric, and phosphoric acids, hydrogen peroxide, most chlorides, and most organic acids. In this respect, it is comparable to titanium, tantalum, Stellite, the Hastelloys, and the stainless steels. For some applications, zirconium is markedly better than any of these since it is resistant to both alkaline and acidic media.

TABLE I—*Physical Properties of Unusual Metals*

	Zirconium	Hafnium	Vanadium	Columbium	Tantalum	Chromium	Rhenium
Atomic number	40	72	23	41	73	24	75
Atomic weight	91.22	178.6	50.95	92.91	180.88	52.01	186.31
Density, pci	0.235	0.472	0.22	0.31	0.60	0.26	1.06
Melting point, deg. F	3360	3600-4000	3150	4380	5425	3430	5756
Crystal structure (RT)	HCP	HCP	BCC	BCC	BCC	BCC	HCP
Allotropic transition, deg. F.	1584-BCC	3540-BCC	None	None	None	HCP[c]	None
Linear coeff. of expansion (microin./in.deg. F at 68° F)	3.0	3.4	4.3	4.0	3.6	3.4	3.6
Thermal conductivity Btu sq ft/hr/in./deg. F	118 (68°F)	--	215 (212°F)	363 (32°F)	377 (68°F)	464 (68°F)	493 (68°F)
Specific heat, Btu/lb deg. F.	0.067	0.035	0.120	.065	0.36	0.11	0.033
Electrical resisitivity, microhm-cm at RT	40-45	32	26.	13.1	12.4	13	19.5
Modulus of elasticity, tension, psi × 10^6	13	20	18.5	30.4[a]	27	36	67.
Recrystallization temp. deg. F 1 hr[b]	930-1020	1300-1400	1380	1920	2330	1470	2550

[a]Subject to confirmation. Values in the literature vary from 12.4×10^6 to 30.4×10^6.
[b]Varies according to degree of cold work.
[c]Below 79°F.

Zirconium has a lower density than stainless steel while its thermal conductivity is about the same. Although zirconium is moderately strong at room temperature, the strength drops rather sharply at elevated temperatures. Alloying counteracts this tendency to a considerable extent. At temperatures above about 900° F, zirconium and the alloys must be protected from prolonged exposure to CO, CO_2, SO_2, steam, hydrogen, and flue gases. Because of the deleterious effects of nitrogen and oxygen, these metals should not be used in air above 1200° F.

Zirconium and its alloys can be fabricated and processed by the standard techniques used for stainless steels and titanium. Hot-working operations must be performed in protective sheaths or atmospheres except for very heavy sections such as ingots and thick plate. In addition to forging, rolling, swaging, drawing, and forming, extrusion is useful for producing pipe, tubing, and complex shapes.

Zirconium is also readily formed by powder-metallurgy techniques. It can be joined by welding under an inert shield or silver brazing in vacuum. Special techniques have been developed for joints to dissimilar metals. With sharp, carbide-tipped tools, zirconium is easily machined when the machinist has been instructed properly. Since fine zirconium chips burn vigorously if ignited, accumulation of these around machines should be minimized.

Industrial applications

Zirconium's use in boiling-water and pressurized-water reactors seems assured for the foreseeable future, since its nuclear properties and corrosion resistance make it nearly ideal for these applications; furthermore, the recently reduced prices increase the margin of advantage of zirconium over other candidate metals. Lower prices will certainly result in extensive use of zirconium for new chemical-processing equipment and related applications where corrosion problems are severe.

Among the devices which have been fabricated of zirconium are: heat exchangers, valves, reaction vessels, agitators, fan blades, and steam ejectors for use with hydrochloric acid. Other applications include alloys, especially with magnesium and as a deoxidant in steels; getters to remove traces of gaseous contaminants from electron tubes; seals of glass and ceramics to metal; and pyrophorics such as flash bulbs, fireworks, and primers for explosives. Potential uses include electrolytic capacitors and rectifiers in place of presently used tantalum, surgical devices for use in the human body, and for hard, corrosion-resistant fountain-pen tips.

HAFNIUM

Hafnium has become available in practical quantities as a result of the atomic-energy program to produce zirconium. The two metals are very similar in nearly all of their properties.

Hafnium occurs in ores with zirconium; in fact, no occurrences are known of one without the other. The hafnium is presently separated as a by-product in the chemical processing of reactor-grade zirconium. Conversion to the metal is accomplished by thermal decomposition of the tetraiodide to form crystal-bar hafnium or by reduction of the tetrachloride with mangensium or sodium. The present price is about $70 per lb.

It absorbs neutrons

In general, hafnium has the properties of zirconium; the most important exception to this is the absorption of thermal neutrons. Pure zirconium absorbs very few neutrons so that it is useful for structural components in reactors, whereas hafnium has an unusually high absorption and is useful for controlling reactors by absorbing excess neutrons. Hafnium also has a higher melting point than zirconium, a much higher allotropic transition temperature, and nearly twice the density. Like zirco-

TABLE II—*Mechanical Properties of Unusual Metals*

Metal and test temp.	Tensile strength, 1000 psi	Yield strength (0.2% offset) 1000 psi	Elongation per cent
Zirconium			
Pure, annealed, RT	34	10	47
Commercial, annealed, RT	50	35	35
Commercial, 40% CW, RT	80	70	13
Zircaloy 2			
Annealed, RT	68	45	22
Annealed, 500°F	32	18	36
Hot-rolled, RT	82	66	42
40% CW, RT	108	99	36
Hafnium			
Pure, annealed, RT	59	22	35
Pure, annealed, 500°F	38	12	51
Pure, hot-rolled, RT	79	63	15
Vanadium			
Commercial, annealed	70	63	32
Commercial, hot-rolled, RT	91		22
Commercial, hot-rolled, 1112°F	40		38
Commercial, hot-rolled, 1832°F	7		50
Columbium			
Commercial, RT	39	24[a]	49
Commercial, 1022°F	32	10.5[a]	24
Tantalum			
Commercial			
Sheet, annealed, RT	50		40
Sheet, worked, RT	110		1
Wire, annealed, RT	100		11
Wire, worked, RT	180		1.5
Chromium			
Pure, annealed, 626°F	41	27	14
Pure, annealed, 1965°F	9	9	104
Rhenium			
Pure, annealed, RT	164	135	28
Pure, worked, RT	322	311	2
Pure worked, 1850°F	124		1
Pure worked, 2700°F	40		1

[a]Proportional limit.

nium, hafnium is unusually resistant to many corrosive fluids but is attacked by air and other gases at elevated temperatures.

When uncontaminated by nitrogen or oxygen, hafnium can be fabricated with nearly the same techniques used for zirconium. It has been forged, rolled, extruded, drawn, machined, and welded successfully.

In addition to its application to control of nuclear reactors, hafnium should be useful in applications where the corrosion resistance of zirconium and high transformation temperature are required.

VANADIUM

Ores of vanadium are both domestic and foreign, with principal United States deposits being in the western part of the country, notably in Colorado and Utah. The commercially purified metal is available in the form of buttons or lumps, and small quantities are being supplied in wrought form for experimental purposes.

Vanadium in button form is sold for approximately $65 per lb., and may be obtained in the form of lumps for $50 per lb. While such prices are relatively high in comparison with many commercial metals, the cost represents a significant reduction from quotations obtained as recently as 1950 of $1800 per lb.

Possible structural applications

In the hot-rolled and annealed condition, vanadium has a pronounced yield point, and its stress-strain curve accordingly resembles that of mild steel. Its density is 0.22 pci and its modulus of elasticity is 18–19 $\times$ 10^6 psi. This interesting combination of properties suggests possible future structural applications.

A body-centered cubic material, vanadium undergoes a transition from ductile to brittle fracture at temperatures of −76° to −338° F, dependent upon oxygen, nitrogen, and carbon content. Low levels of oxygen, nitrogen, and carbon are associated with optimum fracture characteristics.

From the corrosion standpoint, vanadium is resistant to alkaline and hydrochloric-acid solutions, but is not resistant to oxidizing acids such as nitric. Its resistance to salt water and salt spray may be classed as fair to good. There is evidence that it resists pitting by salt water but is subject to general corrosive attack.

The electrical resistivity at room temperature is 24.8 microhm-cm, higher than most of the common metals. It is a poor conductor of magnetic flux.

Vanadium does not work-harden rapidly and may be cold-worked readily. It is a free cutting material and good machining results have been reported with tool characteristics similar to copper. Remelting and welding operations require protective atmospheres to prevent reaction of the metal with oxygen and nitrogen above 550°-600° F. For welds requiring optimum purity, an argon atmosphere is recommended. The material can be hot-worked, and one technique employs an austenitic stainless-steel sheath to protect it from the atmosphere. Fabrication procedures for such composites are similar to those used in the stainless-steel industry.

Vanadium is used as an alloying element in steels. High-purity vanadium has been rather extensively investigated by the Atomic Energy Commission, but its value in such applications is uncertain. The metal is currently used as a target in x-ray tubes, and its broader utility as an engineering material presents interesting possibilities. The relatively high electrical resistivity, combined with an intermediate density and modulus of elasticity, merits consideration.

COLUMBIUM

The availability of columbium (niobium) has changed from acute shortage to abundant supply. Ten million pounds of concentrates were produced during 1954, and the United States imported over 80 per cent of this total. Nigeria has been the most important source of columbium ores. Canadian deposits of substantial extent have been discovered,

and steps are being taken to insure domestic availability. A principal domestic supplier is expanding facilities to increase production 150 per cent.

The bulk of columbium powder is produced to a specification calling for a minimum of 99.5 per cent columbium, with stringent requirements on the quantities of many minor elements.

To obtain further purification, the powder may be processed such that its carbon content is slightly greater than 0.1 per cent. Upon subsequent arc melting, the excess carbon reacts with oxygen and facilitates oxygen removal. In massive form, a higher purity 99.8 per cent minimum columbium can be produced by high-temperature sintering; this product can be fabricated or used as consumable electrodes in arc melting.

Columbium powders and granules are now being supplied by several manufacturers, and wrought forms are available on special order. Sheet, strip, foil, wire, rods, and other shapes can be produced by powder metallurgy or arc-melting followed by cold-working. Tubes may be made by forming and welding of strip. Pressed and sintered arc-melting electrodes are also available. Powder costs, dependent on quantity and purity, vary from $43 to $76 per lb. The cost of fabricated product such as sheet and strip is approximately $90 per lb.

For nuclear applications

The low thermal neutron capture cross section of columbium (1.2 barns) makes it attractive for nuclear applications, and it is being used as the canning material for fuels in experimental reactors. It does not work-harden rapidly and can be cold-rolled and formed readily. It is resistant to acid corrosion, although it is inferior to tantalum in this respect. The material has strength at 2200° F comparable to that of pure molybdenum, and has an attractive density (0.31 pci) in comparison to other refractory metals. Columbium is embrittled by nitrogen, and this phenomenon has hampered its ready acceptance as a high-temperature structural material. It is a superconductor at temperatures below 8 K, having the highest superconducting temperature of any known element with the exception of technicium (11.2 K).

Most of the procedures for working and fabricating, and deep-drawing operations are done at room to gall during machining. Forming, bending, stamping, and deep-drawing operations are done at room temperatures so as to avoid embrittlement resulting from reaction with gases at elevated temperatures. It can be softened by vacuum annealing, with high vacuums required to avoid gas contamination. Columbium can be welded to itself by resistance welding and inert-arc welding. A properly made weld is ductile. It may be chemically cleaned with hot chromic acid.

An alloying agent

Currently, there are no commercial applications for columbium except as an alloying agent. Considerable experimental work is being directed toward the development of columbium-base alloys for elevated-temperature structural applications as well as nuclear applications. Possibilities also exist for its use in electrolytic capacitors and in Cryotrons for computer application.

TANTALUM

Tantalum ores are associated with columbium deposits, and the majority of concentrates come from Africa. There are also small producing deposits in Brazil and western Australia. Tantalum is potentially in shorter supply than columbium. A five-fold increase in tantalum consumption, presently estimated at 50 tons per year in the United States, appears to be about all the present deposits would supply. This would require the use of lower grade concentrates with increased production costs.

Tantalum is converted into massive form by sintering in vacuum. The powder is pressed into bars, and resistance heating under vacuum consolidates the metal to a density which is 90 per cent of theoretical. Subsequent working by forging or rolling essentially eliminates porosity and the product approaches 100 per cent theoretical density.

Commercial forms

Tantalum is available in various forms such as rod, sheet, wire, and foil. Tubing may be produced by welding on special order. The cost of tantalum powder varies from $46-$60 per lb. according to desired purity and size of order. Fabricated forms are available at approximately $70 per lb.

Tantalum has exceptional resistance to corrosion by acids such as hydrochloric, nitric, sulfuric, and phosphoric. It forms anodic oxide films which are of exceptional stability below 300° C (572° F). It oxidizes readily above this temperature, however, and alloy development or protective coatings will be required for elevated-temperature service in air. It has a low vapor pressure at 2225° C, being superior to other refractory metals in this respect with two exceptions (rhenium and tungsten). Tantalum may be welded to itself and certain other metals by resistance welding. Seam-welding is usually done under water to prevent oxidation of the metal. Light welding pressures should be used, since heavy pressures lead to so little resistance across the joint that no weld is made. Tantalum also can be joined by inert-arc welding.

The metal can be annealed by heating in vacuum to above 1275° C (2327° F), its recrystallization temperature. Cold-forming is preferred because of its oxidation characteristics. In lathe operation, high cutting speeds using high-speed tools are preferred. Slow speeds will cause the metal to tear. Carbon tetrachloride is recommended as a cutting medium, and the work must be kept flooded at all times. The

metal also can be milled, drilled, threaded, and tapped. Grinding is difficult.

Corrosion resistance

The most important uses for tantalum are based on its corrosion resistance. It is used in the chemical industries for the processing of such materials as chlorine, hydrochloric acid, chlorides, and nitric acid. Applications include heat exchangers, condensers, coils, and bayonet heaters. Immune to body chemicals, it has been used for implants in humans.

Tantalum is used in electronic tubes, where its high melting point, low vapor pressure, gettering properties, and copious electron emission at reduced power levels are advantageous. Tantalum electrodes are used in electrolytic rectifiers, and tantalum sheet is being employed in capacitors. The oxide film which acts as the dielectric is formed on tantalum by anodic oxidation prior to assembly. The future should see continued usage of tantalum in these and related applications utilizing its exceptional corrosion resistance, the good dielectric characteristics of its oxide, and other unusual properties.

CHROMIUM

The emergence of chromium and chromium-base alloys for structural and other applications is recent.

Major deposits of chromite, its principal ore, are located in Russia, the Union of South Africa, Southern Rhodesia, Turkey, and Cuba. Nearly all of the chrome ore used annually in the United States is imported. However, numerous small and low-grade deposits are known in the United States which can be worked under conditions of national emergency.

A number of vendors supply chromium powder. Wrought forms may be obtained in experimental quantities.

The cost of chromium powder is $1.50 to $5.50 per lb. dependent on purity and quantity.

Table I shows that chromium undergoes an allotropic change at 79° F. In addition, a second allotropic transformation probably occurs at a temperature approximately 100° C below its melting point, consisting of a transition from the normal body-centered crystal structure to face-centered cubic.

Brittle and reactive

The primary deterrent to commercial structural application of chromium has been its room-temperature brittleness caused by nitrogen impurities. Carbon is also thought to have deleterious effects. The oxidation resistance of chromium is good at elevated temperatures but inferior to nickel-chromium alloys.

Because of its reactive nature, chromium must be melted in vacuum or in an inert atmosphere. The molten metal is usually superheated to obtain sufficient fluidity, and casting temperatures are approximately 2000° C (3632° F). Prior treatment of the furnace charge at elevated temperatures in pure dry hydrogen removes sufficient gaseous impurities to facilitate the casting process. Resultant ingots are hot-worked by extrusion, forging, and swaging. Sheaths are sometimes used to prevent contamination. Powder-metallurgy processes also may be used for consolidation.

Development priority has been given to the production and properties of chromium, and only limited work has been done in the joining, forming, and machining areas. It recently has been established, however, that brittle cold-worked chromium can often be made ductile by etching away the surface. This may be performed anodically in an orthophosphoric-acid sulfuric-acid bath or by direct immersion in hydrochloric-acid solution. The effect is attributed to the removal of heavily nitrided surface layers formed during fabrication.

The potentialities of chromium and chromium-base alloys for structural application are not regarded as good at the present time. Work is continuing in the area, however, and a technical breakthrough is definitely within the realm of possibility. It is considered likely that the initial application of chromium-base alloys will be in other areas such as bearings, tool materials, and die materials, wherein high hardnesses developed by surface reactions with nitrogen can be employed advantageously.

RHENIUM

Only during the past three or four years has the technology been acquired which now promises to make rhenium a commercial product.

The principal source of rhenium is the flue dust obtained on roasting a copper ore found in Arizona. If desired, rhenium powder of 99.95 per cent purity can be obtained.

The best method for consolidating the powder is by pressing and sintering, although arc-melting is useful in certain applications. Crystal-bar rhenium can be obtained by thermal decomposition of the pentachloride; this method can also be used successfully to plate base metals if careful control is maintained.

A difficult metal

Rhenium is difficult to fabricate, but recent work has demonstrated that special techniques can produce bars, strip, foil, and wire from the sintered powder. Arc-melted and crystal-bar rhenium, however, can be worked only slightly before failure. Because of hot shortness, rhenium cannot be hot-worked and, instead, must be cold-worked with frequent anneals at about 3100° F since cold-working to 30 per cent area reduction triples the hardness of the metal. Despite these difficulties, 0.003-in. foil and wire have been fabricated. At present, rhenium powder is quoted at about $2000 per lb.; no doubt the price reflects a lack of demand and will be reduced as production is increased.

The outstanding property of rhenium is its combination of high melting point, low vapor pressure, ductility at room temperature, and very high strength.

Among the unusual physical properties of rhenium are its density, the fourth highest among the elements; its melting point which is second only to graphite and tungsten; and its vapor pressure which is much lower than that of either tantalum or tungsten. Although it oxidizes catastrophically on heating in air, it is very stable in hydrogen or vacuum.

Rhenium, unlike tungsten, is not attacked by the "water cycle" which produces failure of tungsten filaments in vacuum tubes by continuously depositing tungsten on the cool tube walls. Rhenium has been shown to be resistant to molten tin, zinc, copper, and silver, although it fails in aluminum, nickel, and iron. It is also unattacked by aluminum oxide during 7000 hours at 2900° F.

Many of the mechanical properties of rhenium are notable. Its modulus of elasticity is exceeded only by osmium and iridium; its tensile strength at room temperature is higher than that of tungsten; it is appreciably ductile at room temperature in contrast to tungsten. At elevated temperatures, the ductility of rhenium is poor, although in tensile and creep-rupture properties it is superior to tentalum, columbium, and tungsten up to at least 2500° F.

A wide potential

The potential applications of rhenium include electron tubes, and contacts in electrical relays and switches. The use of rhenium in electron tubes is attractive because of its inertness to the water cycle, its strength, and its refractory nature. The applicability of the metal and several binary alloys with tungsten and molybdenum is currently being investigated.

Rhenium as a contact metal has already been put to limited use in magnetos for marine engines. In this case, its resistance to corrosion in salt water combined with its resistance to electrical erosion, and its high strength and ductility make rhenium especially attractive. Its use is indicated for other applications requiring these properties such as pen points. For measurement of very high temperatures, thermocouples of rhenium with tungsten or molybdenum are usable to about 4500° F.

The University of Chicago has received a grant from the National Science Foundation for high energy nuclear particle research in the upper atmosphere. Unmanned balloons, attaining altitudes of over 100,000 feet will carry gondolas containing stacks of photographic sheet emulsion containing heavy atomic nuclei. High energy particles from outer space, colliding with these nuclei, will leave a record of their collisions in the photographic emulsion. Information will thus be gained as to the nature and energy of such particles which is not possible to obtain under the protective mantle of the atmosphere.

—from INDUSTRIAL LABORATORIES
November, 1958

"TRANSACTIONS OF THE A.S.M.E."

HEAT TRANSFER STUDIES OF NAVAL BOILERS

ACKNOWLEDGEMENT

This article is an abridged version of a paper written by L. Cohen and W. A. Fritz, Jr., of the Heat Power Division, Naval Boiler and Turbine Laboratory, Philadelphia, Pennsylvania. The paper was published in the April 1958 "Transactions of the A.S.M.E."

REASONS FOR A GAS-TEMPERATURE PROFILE

THE FIRST single-furnace integral superheater boilers tested at the Naval Boiler and Turbine Laboratory after World War II were from 50° F high to 200° F low in superheat. Succeeding boilers tested have usually had either high or low temperatures, only a few having initially met requirements. Modifications have sometimes required installation of new superheaters. This is expensive and time consuming since construction of new boilers, and even their shipboard installation, generally takes place concurrently with Laboratory tests. Modifications of a less drastic nature have involved one or more of the following:

(*a*) Removal of water screen tubes ahead of superheater.

(*b*) Addition, removal, or rearrangement of gas baffling before and after superheater to change gas flow and its distribution.

(*c*) Changing steam flow characteristics through superheater by installing orifices in certain tubes or bypassing some of the flow around certain tube passes.

Other factors and problems, some directly and others remotely related to the single-furnace design, arose. Superheaters were located nearer to the furnace, some with only two rows of screen tubes between them and the furnace. Relatively constant superheat temperature resulted since radiant and convection heat transfer to superheater complemented each other. Steam pressures and temperatures and furnace heat release rates were increased. These changes necessitated the use of new and better materials for superheater tubes and their supports, gas baffles, drum and header protection plates, and soot blowers.

A continuing program in the Navy is reduction of size and weight of boilers per pound of steam produced. One method of accomplishing this is to decrease number of downcomer and riser tubes. This requires a close knowledge of heat absorption in furnace water wall areas to assure adequate circulation. Use of fuel oil with an increased amount of sulfur and vanadium has increased slag and corrosion problems. Resultant fireside deposits are affected by both magnitude and distribution of combustion gas temperatures.

DESCRIPTION OF NAVAL BOILERS

To evaluate these problems, the Naval Boiler and Turbine Laboratory undertook a program for obtaining gas-temperature profiles in boiler firesides and data necessary to conduct heat-transfer studies

in naval boilers. The four boilers chosen for this program have been of the single-furnace design. They differed in operating pressures and temperatures and in certain design details, such as gas baffling and tube layout, but their general configuration, shown in Figures 1 and 2, was as follows:

(*a*) A furnace, oil fired from the front, with rear and side water walls and refractory front and floor.

(*b*) Two to four rows of 2-in. water-screen tubes dividing furnace from superheater.

(*c*) A cavity in which was located the superheater consisting of 1 to 1½-in. horizontal U-tubes connecting to headers in rear of boiler. Entrance and exit of superheater cavity was baffled to direct gas flow over superheater to obtain desired steam temperature and to protect tubes, supports, drums, and headers from excessive temperatures.

(*d*) A main evaporative bank consisting of from 20 to 25 rows of 1-in. tubes extending from the steam drum atop the boiler to the water drum at the bottom. This bank, consisting of about 1000 tubes, was broken by one or two cavities about 4 in. in width for location of soot blowers.

(*e*) An extended surface economizer located in the uptake.

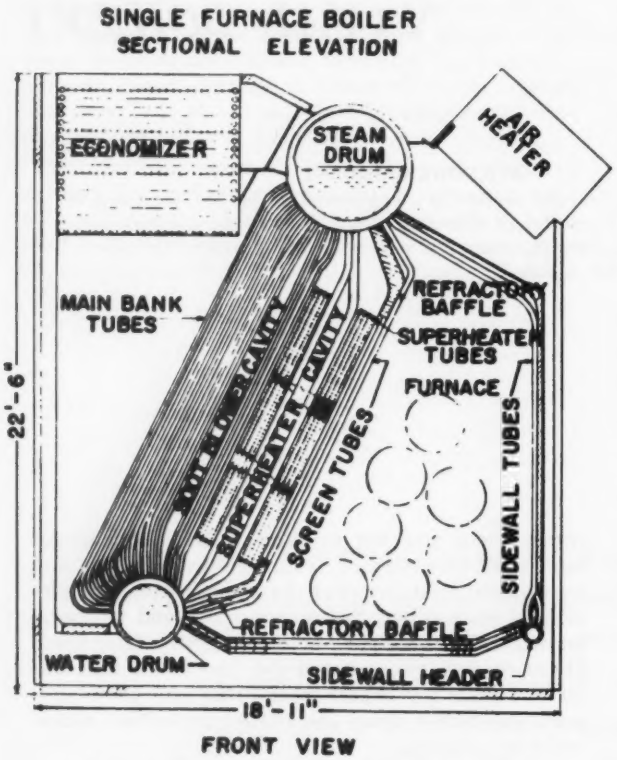


Figure 1. Single-furnace boiler sectional elevation.

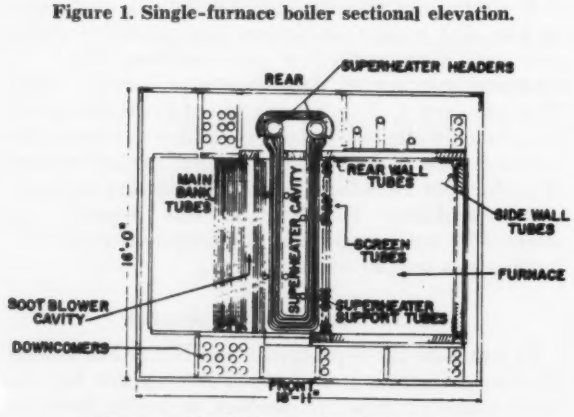


Figure 2. Single-furnace boiler plan view.

DIFFICULTIES IN OBTAINING A PYROMETER

The major problem to confront the Laboratory in obtaining a boiler gas-temperature profile was to obtain a satisfactory probe type pyrometer. The primary difficulty is one of space consideration. Many sections to be traversed in naval boilers permit use of a probe having a diameter no larger than 1 in. In addition, the probe can be supported at only one end, yet must be suitable for horizontally traversing a distance of 9½ feet without sagging.

Other problems in pyrometer design are high temperatures (to 3000° F) and highly corrosive constituents of fuel oil, namely, vanadium and sulfur. Additionally, velocities and pressures of combustion in naval boilers are relatively low as compared to other applications for similar type probes.

Two other requirements which are basic, but of paramount importance in any probe design, are accuracy of temperature indication and reliability of performance. It was considered by the Laboratory that a probe should provide, at the very minimum, eight continuous hours of service without failure, with a goal of fifty hours of intermittent service.

DESCRIPTION OF PROBES

Probes used by the Boiler and Turbine Laboratory are 1 in. in diameter, water cooled, and designed to aspirate gases of combustion over the thermocouple hot junction at a velocity greater than that of the free gas stream. These probes, initially designed by the National Bureau of Standards, have undergone modification at the Laboratory as use has shown alterations to be necessary. The probe, as shown in Figures 3 and 4, consists of the following:

(*a*) A thermocouple (chromel-alumel or platinum-platinum, 10 per cent rhodium) insulated with a two-hole porcelain tube which is installed in a thin-walled Inconel tube or well welded shut at the end.

(*b*) Three coaxial tubes, the inner one of ½-in.-OD stainless steel, houses the thermocouple and well and provides passage for aspirated gases. The intermediate tube of ¾-in-OD stainless steel and the outer tube of 1-in.-OD cold-rolled steel provide passages for flow of the cooling water.

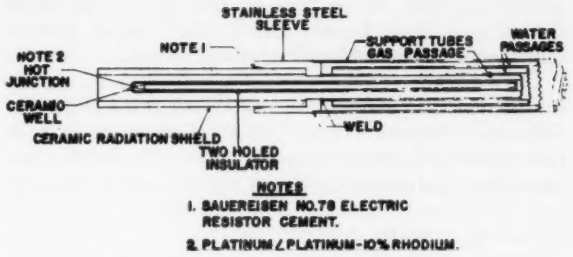
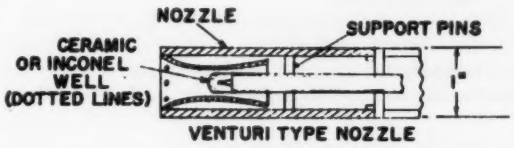


Figure 3. High-velocity thermocouple probe.



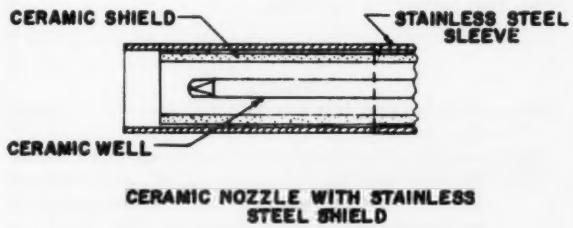


Figure 4. High-velocity probe radiation shields.

(*c*) A nozzle section or radiation shield at the extreme end of the probe in which is centered a thermocouple well. The nozzle has an outer cylinder and inner bell-shaped or venturi-type section in which is located the thermocouple hot junction. Gases of combustion are aspirated through both the bell-shaped section over the thermocouple well and, by way of eight holes, through an annular section between the outer cylinder and the venturi section. A nozzle of this type was required in lieu of a multiple-type radiation shield because of:

1. Small size of openings in tube banks.
2. Danger of breaking nozzles in these small openings.
3. Very high gas temperatures involved.

(*d*) A probe head which acts as a terminus or collecting point for thermocouple, well, and coaxial tubes, and provides connections for cooling water and aspirated gases.

BOILER DESIGN PARTICULARS

Design particulars of boiler used for remaining discussions in this paper are as follows:

Full power steam capacity = 261,450 lb/hr

Final steam temperature = 950°F, + 50°F, − 0 at all rates from 45 to 100 per cent full power

Pressure at superheater outlet = 1200 psig

Oil burners = 7 wide range return flow type

Total heating surfaces	15,440 sq ft
Generating surface	6,437 sq ft
Rear wall	90 sk ft
Side wall	150 sq ft
Main bank	6,197 sq ft
Economizer surface	7,335 sq ft
Superheater surface	1,668 sq ft
Radiant heat absorbing surface	400 sq ft
Rear wall	90 sq ft
Side wall	150 sq ft
Fireside row tubes	160 sq ft
Average gas flow area through superheater	35 sq ft
Average gas flow area through generating bank	52 sq ft

Furnace dimensions
- Depth = 9 ft 6 in.
- Volume = 910 cu ft

Heat release rates at full power
- KB/sq ft RHAS/hr = 927
- KB/sq ft THS/hr = 24
- KB/sq ft FV/hr = 408

Distance between tubes
- Water screen = 1½ in.
- Superheater = ½ to ¾ in.
- Main generating bank = ¾ in.

FURNACE EXIT TEMPERATURE AND HEAT TRANSFER

Of all temperatures obtained, those at the furnace exit are among the most valuable because of importance of furnace heat absorption in design of naval boilers. Heat absorption in the furnace is primarily by radiation to furnace waterwall and screen tubes with some convection heat transfer to latter.

To determine furnace heat absorption it is necessary to know furnace exit temperatures. These can be calculated by using formulas based on the Stefan-Boltzmann law which states that radiant heat absorption is proportional to difference between fourth powers of absolute temperatures of radiating and receiving bodies. Accurate calculation of gas temperature leaving furnace, however, is impossible because of many variables concerned. These include: Emissivity of surface, flame temperature, effectiveness of radiant heat absorbing surfaces, partial pressures of products of combustion, radiant beam length, heat content of fuel, and general overall furnace configuration. Designers usually arrive at approximate furnace exit temperatures, but only by actual measurement may these be accurately determined.

Figure 5 shows results of a gas pyrometer traverse of the furnace exit during boiler operation at 120 per cent full-power steam rate. Temperature varied from 2300° F to 3200° F, demonstrating that a calculated temperature could differ considerably from highest temperatures. This high variation in temperature carries on throughout the gas path and is especially important when it comes to selection of materials for boiler construction.

Figure 6 shows effect of excess air upon furnace exit temperature at boiler firing rates from 20 to

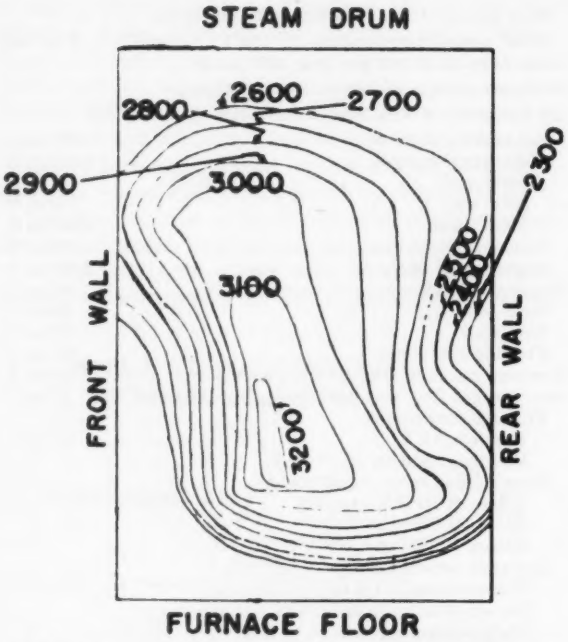


Figure 5. Temperature traverse of furnace exit. Boiler at overload (120 per cent of full power) conditions.

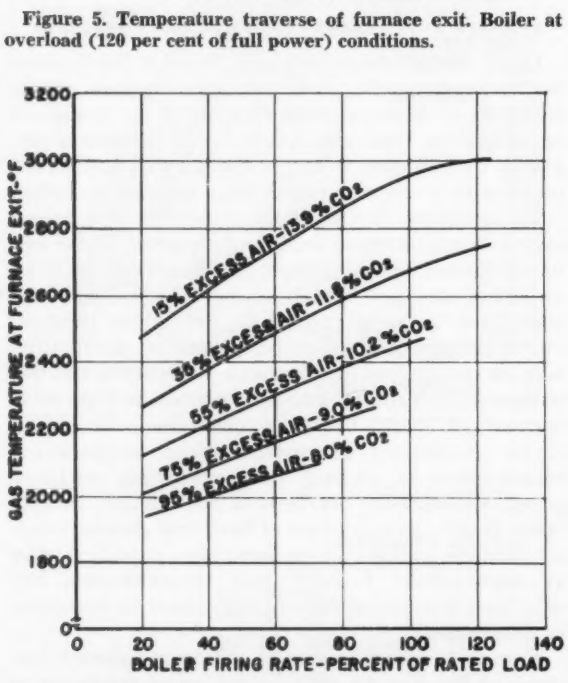


Figure 6. Effect of excess air and firing rate upon furnace exit gas temperature.

120 per cent of full power. Temperatures are from 400° F to 800° F lower (dependent upon firing rate) when excess air is raised from 15 to 95 per cent. This provides some indication of necessity of maintaining minimum amount of excess air. By "setting the stack for an efficiency haze" (which means to adjust air flow to oil flow so that smoke at stack outlet is a faint brown haze) most naval boilers operate with 20 to 25 per cent excess air.

Once furnace exit temperatures have been determined, furnace absorption can be obtained from the difference between heat released in furnace and heat leaving furnace. The net heat released in furnace can be determined from the following formula

$$Q_1 = R(H_1 + W_a(t_a - t_0)C_{pa}$$

where

Q_1 = net heat released, Btu/hr
R = fuel rate, lbs/hr
H_1 = lower heating value of fuel, Btu/lb
W_a = lbs of air/lb of fuel
t_a = temperature of air at burners, deg F
t_0 = temperature of air at forced draft blower outlet, deg F
C_{pa} = specific heat of air, Btu/lb/deg F

All of these factors can be obtained from measured test data.

Using the furnace exit gas temperatures, heat in the gases leaving the furnace can be determined from the following formula

$$Q_2 = R\,W_g h_g$$

where

Q_2 = heat leaving furnace, Btu/hr
R = fuel rate, lbs/hr
W_g = weight of total products of combustion/lb of fuel
h_g = sensible heat of total products of combustion at furnace exit temperature above air temperature at forced draft blower discharge, Btu/lb of gas

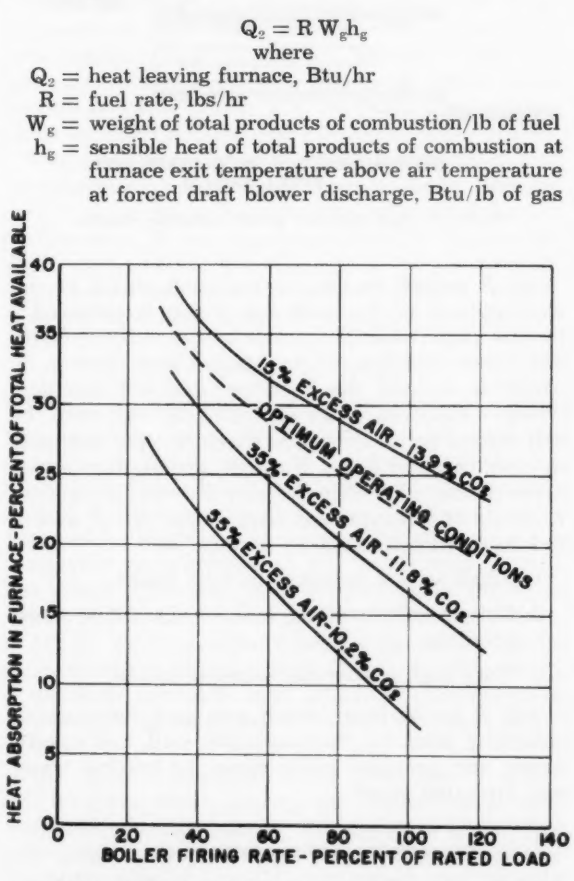


Figure 7. Effect of excess air and firing rate upon heat absorption in furnace.

Then

$$Q = Q_1 - Q_2$$

where Q = heat absorbed in the furnace in Btu/hr

Figure 7 shows effects of excess air upon furnace heat absorption at boiler firing rates from 20 to 120 per cent of full power. Furnace heat absorption decreased with firing rate, but even at maximum boiler load under optimum operating conditions, the furnace absorbs 20 per cent of all heat available (refer to dashed curve, Figure 7). At lower rates heat absorbed in furnace accounts for over 35 per cent of total available.

Increases in excess air considerably lower furnace heat absorption rates. Additional air reduces the adiabatic temperature and, in accordance with the Stefan-Boltzmann law, lowers furnace temperatures and absorption.

The importance of heat absorption in furnace can be illustrated by Figure 8 which shows heat absorption in all boiler sections. To 78 per cent of full boiler load, heat absorbed in furnace is greater than that in any other single boiler section.

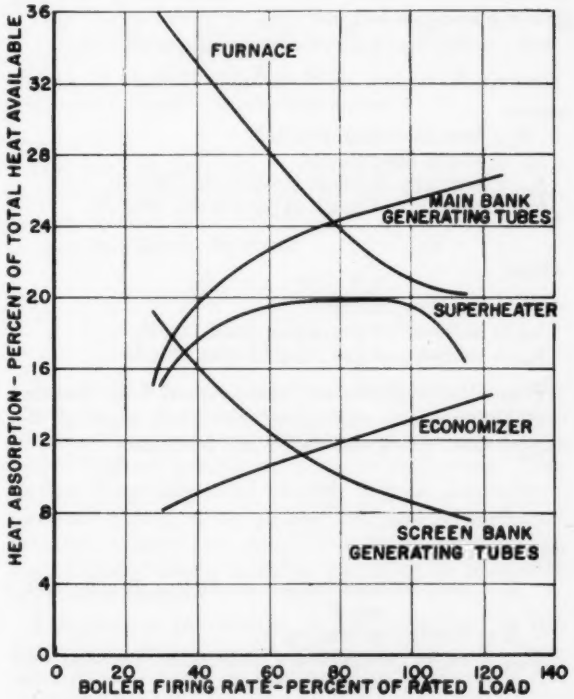


Figure 8. Heat absorption in various boiler components.

SUPERHEATER GAS TEMPERATURE AND HEAT TRANSFER

Design of superheaters is both important and difficult—difficult because desired temperature must be designed into superheater without aid of positive controls during operation—important because attaining of desired steam temperature is necessary to meet steam plant requirements. Considerable savings in weight and space can be realized by accurate design of superheaters.

An example of need for more information as to phenomena occurring in the gas path of superheaters is a recent Laboratory occurrence. Because of severe wear of superheater tube supports, 85 per cent of the height of one of the support tiers was completely encased in refractory so as to lengthen support life. The refractory pier was 6 in. wide and covered little more than 2 per cent of the superheater surface. Calculations indicated resultant temperature of steam leaving superheater would not change more than 2° F because decreased surface area would almost be counterbalanced by increased heat transfer in smaller flow area available. Actual boiler operation revealed, however, a final steam temperature drop varying from 20° to 40° F, depending upon boiler rate. With removal of refractory, steam temperatures returned to normal. Apparently, the refractory pier had changed the gas-temperature profile to an extent where theory alone was not sufficient to predict steam temperatures.

In the latest type boilers, having three rows of screen tubes, it is exceedingly important to know furnace exit temperatures in order to design the superheater. While superheaters in these types of boilers are basically of convection type, their proximity to the furnace results in sufficient radiant heat transfer to complement convection heat transfer.

Calculations made from gas temperatures obtained during heat-transfer studies of the *Saratoga* test boiler revealed that heat absorption in the superheater decreased as excess air was increased, as shown in Figure 9. Generally in convection-type superheaters increased excess air results in in-

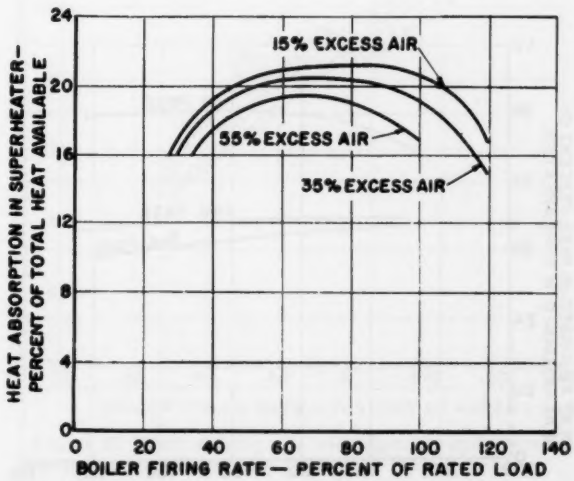


Figure 9. Effect of excess air and firing rate upon heat absorption in superheater.

creased heat absorption, since increase in weight of products of combustion flowing over the superheater more than compensates for lower gas temperatures. In the type boiler discussed, where superheater is affected by radiant heat transfer from furnace, lower gas temperatures resulting from more excess air have a greater effect than does increased heat by convection, resulting in reduced heat absorption and lower steam temperatures.

Gas temperatures at superheater inlet, in cavity, and at outlet were measured as previously discussed. Figure 10 indicates a gas-temperature profile obtained across the superheater midway through the gas path during a 120 per cent full power test. These were the highest temperatures obtained during any test and show that gas temperatures as high as 2900° F were measured at superheater inlet. This temperature is considerably in excess of that anticipated and illustrates need for intensifying search for higher temperature materials for superheater tubes and supports.

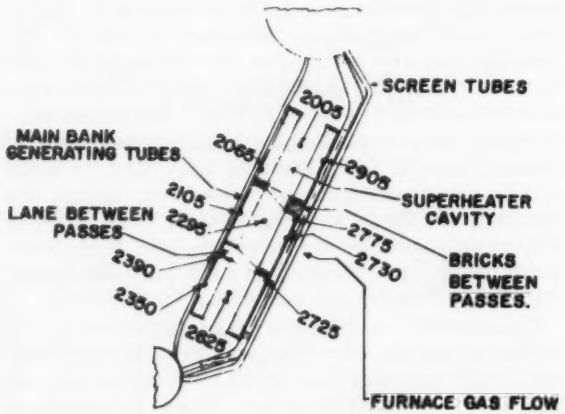


Figure 10. Gas-temperature profile in superheater midway through gas path. Boiler at overload (120 per cent of full power) conditions.

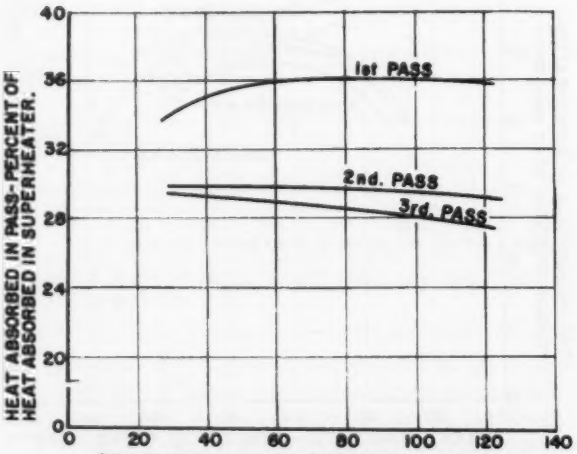


Figure 11. Heat absorption in superheater passes.

Gas temperatures before the superheater were highest at the top in the vicinity of first steam pass, while those at exit were higher at the bottom in second and third passes. Apparently a gap or lane between the second and third passes caused by junction of intermediate and outlet superheater headers on exit side of the superheater was acting as an orifice and drawing an increased flow of gas. (The lane between first and second passes on entrance side of superheater had previously been bricked up because of excessive tube temperatures in that region.) Heat absorption in the first pass was 20 per cent higher than in the other two, as is indicated by Figure 11, although its surface area was only 14 per cent more.

Steam temperatures were measured in superheater headers to obtain temperatures at entrance and exit of each pass. Heat absorption in each pass of superheater could then be measured by either of two methods as follows

$$\text{a:} \qquad Q = W_s(h_{is} - h_{os})$$

where

Q = heat absorbed, Btu/hr
W_s = steam flow, lbs/hr
h_{is} = enthalpy of steam at pass inlet, Btu/lb
h_{os} = enthalpy of steam at pass outlet, Btu/lb

$$\text{b:} \qquad Q = W_g(h_{ig} - h_{og})$$

where

W_g = gas flow, lbs/hr
h_{ig} = enthalpy of gas at pass inlet, Btu/lb
h_{og} = enthalpy of gas at pass outlet, Btu/lb

From this information, the over-all heat transfer coefficients were calculated for each pass of the superheater using the following formula

$$U = \frac{Q}{S\triangle T_{mtd}}$$

where

U = over-all heat transfer coefficient, Btu/hr sq ft deg F
S = heating surface, sq ft
$\triangle T_{mtd}$ = mean temperature difference causing heat transfer, deg F

Because the first and third passes of the superheater had parallel flow of gas and steam their mean temperature differences were calculated as follows

$$\triangle_{mtd} = \frac{(T_1 - T_3) - (T_2 - T_4)}{\log_e \dfrac{(T_1 - T_3)}{(T_2 - T_4)}}$$

where

T_1 = gas temperature before pass, deg F
T_2 = gas temperature after pass, deg F
T_3 = steam temperature at entrance of pass, deg F
T_4 = steam temperature at exit of pass, deg F

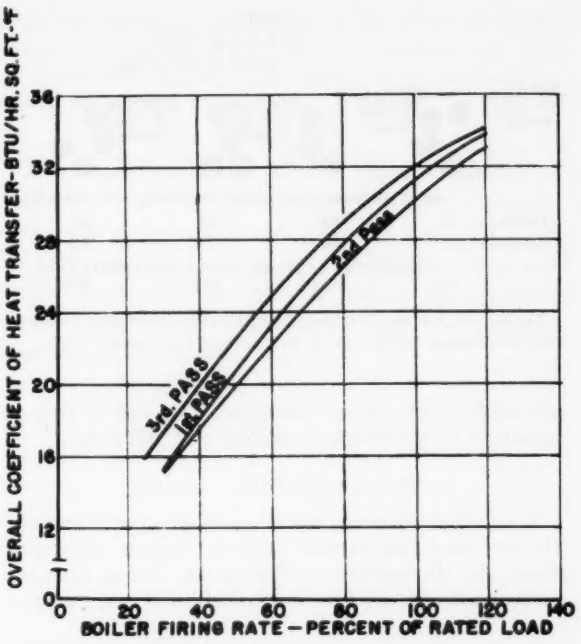


Figure 12. Effect of firing rate upon over-all heat-transfer coefficients for various superheater passes.

The second pass had counterflow of gas and steam and formula for mean temperature difference was as follows (with all symbols as defined above for parallel flow)

$$\Delta T_{mtd} = \frac{(T_1 - T_4) - (T_2 - T_3)}{\log_e \dfrac{(T_1 - T_4)}{(T_2 - T_3)}}$$

Figure 12 is a plot of over-all heat-transfer coefficients for each superheater pass. As expected, coefficients for third pass were highest because this is where highest temperature steam is flowing. This further illustrates why parallel flow of products of combustion and steam in the last pass is preferred because counterflow would result in even higher heat transfer rates, possibly resulting in excessive tube temperatures.

The greater percentage of heat absorbed in the first pass because of the higher entering gas temperatures resulted in heat-transfer coefficients exceeding those of second pass.

MAIN EVAPORATIVE BANK GAS TEMPERATURES AND HEAT TRANSFER

Generating tube banks are relatively simple to design. Almost all heat transfer in the main bank is by convection with some radiation due to intertube reaction and small soot blower cavity. Accurate gas-temperature information is important to determine number of tube rows required. As number of tube rows increases, stack temperature and losses de-

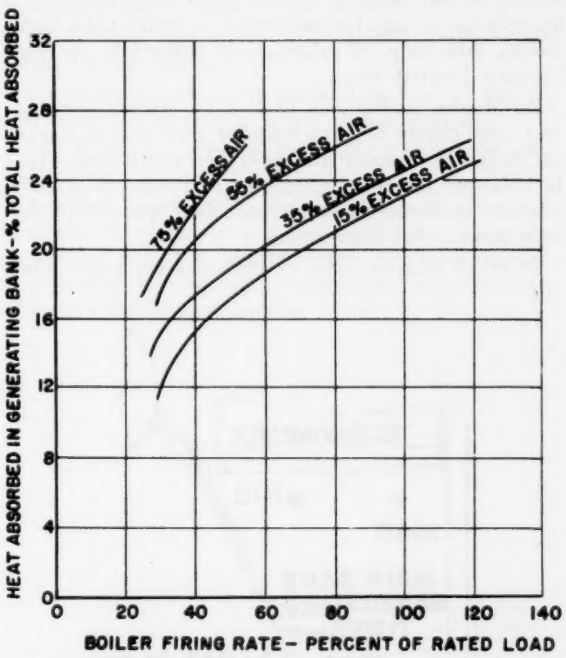


Figure 13. Effect of firing rate and excess air upon heat absorption in main bank generating tubes.

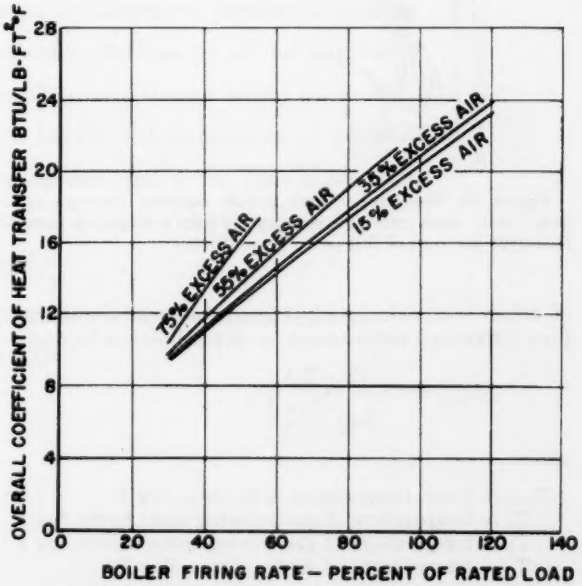


Figure 14. Effect of firing rate and excess air upon over-all heat-transfer coefficients for main bank generating tubes.

crease, but an excessive number of tubes would result in too large a steam drum. Additionally, a knowledge of gas temperatures in main tube bank cavity will help in selection of materials for soot blowers located there.

As shown in Figures 13 and 14, heat absorption and coefficients of heat transfer increase as excess air is raised. Greater gas mass flow more than counterbalances lower temperature of products of combustion, particularly since most heat transfer in this tube bank is by convection.

Over-all heat-transfer coefficients for main bank

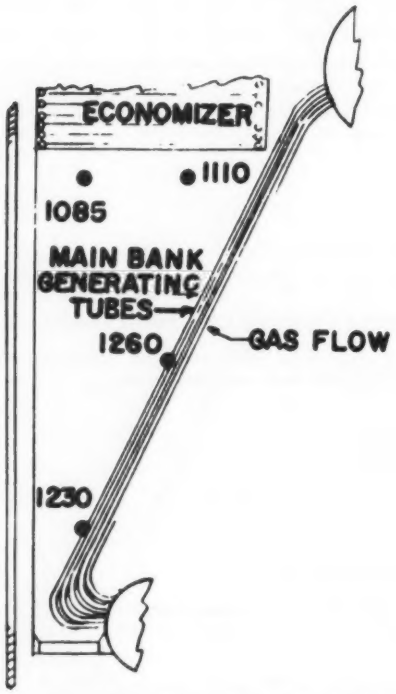


Figure 15. Gas-temperature profile midway through gas path (main bank exit and economizer inlet). Boiler at overload (120 per cent of full power) conditions.

of tubes was calculated utilizing a mean temperature difference determined by the following formula

$$\triangle T_{mtd} = \frac{(T_1 - T_s)}{\log_e \frac{(T_2 - T_s)}{T_1 - T_2}}$$

where

$\triangle T_{mtd}$ = mean temperature difference, deg F
T_1 = temperature of gas entering main bank, deg F
T_2 = temperature of gas leaving main boiler, deg F
T_s = temperature of boiler water, deg F

It should be noted that a considerable drop in gas temperature is experienced between exit of main generating tube bank and economizer inlet. Figure 15 shows that this drop is upward of 150° F for 120

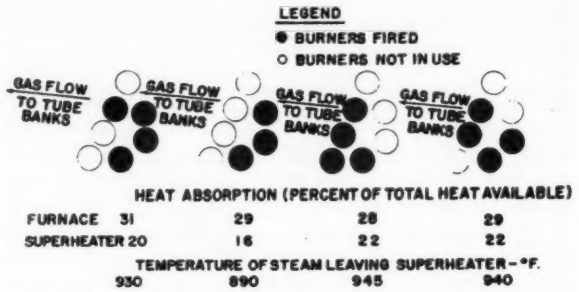

LEGEND
BURNERS FIRED
BURNERS NOT IN USE
GAS FLOW TO TUBE BANKS
GAS FLOW TO TUBE BANKS
GAS FLOW TO TUBE BANKS
GAS FLOW TO TUBE BANKS
HEAT ABSORPTION (PERCENT OF TOTAL HEAT AVAILABLE)
FURNACE 31 29 28 29
SUPERHEATER 20 16 22 22
TEMPERATURE OF STEAM LEAVING SUPERHEATER - °F.
930 890 945 940

Figure 16. Effect of burner combination upon heat absorption in furnace (boiler at 45 per cent of full power rate).

per cent of full power condition. This loss is due to radiation to surrounding casing and refractory.

EFFECT OF CHANGING BURNERS

A number of tests were made at approximately 45 per cent full power varying burner combinations. As illustrated in Figure 16, using burners further away from tube banks will increase furnace

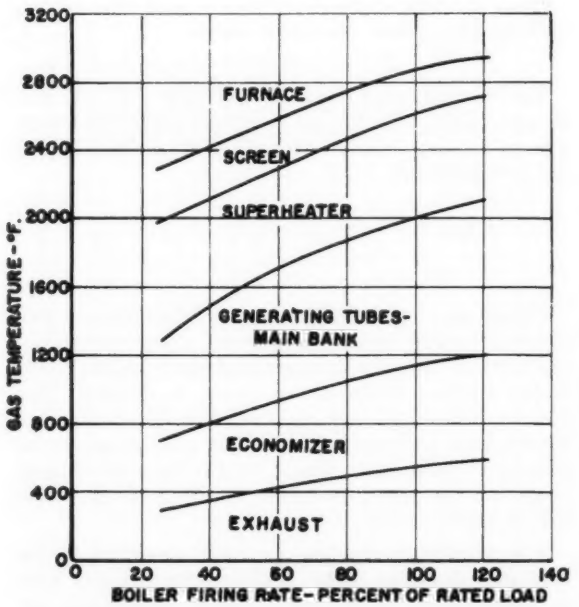


Figure 17. Effect of firing rate on average temperatures in gas path.

heat absorption and decrease absorption in the superheater, thereby reducing temperature of steam leaving superheater. This emphasizes importance of burner combination for nonsuperheat control boilers.

SUMMARY OF GAS TEMPERATURES

A summary of the gas temperature obtained at all rates with the boiler at optimum operating temper-

atures is presented in Figure 17. Average temperatures at the furnace exit, and at entrance and exit of the screen, superheater, main bank, and economizer are shown.

CONCLUSION

The studies described in this paper are continuing. Results are of special interest to the manufacturer and designers of naval boilers and data from the tests are available to them. Although these gas temperatures and heat-transfer studies are relatively new for naval installations they are already showing their value in:

(*a*) Improved types of superheater tube supports and materials.

(*b*) Closer approach to desired superheater steam temperatures.

(*c*) More constant steam temperature at the superheater outlet over a wider range of rates.

(*d*) Improved types of gas baffling at superheater and drums.

Another result of tests conducted to date has been the development and refinement of a gas pyrometer and radiation shield which provides satisfactory service for the highly specialized requirements of marine boiler application.

Recently launched in England, the British cross channel ferry "Maid of Kent" embodies three features which are attracting increasing interest in ship design. First, the use of two full decks and one half-deck, inter-connected with ramps and provided with turntables, illustrates the careful attention being given to vehicular cargo problems — problems which have military logistics implications. Secondly, the use of active anti-roll stabilizing fins is indicative of the increasing importance being given to reduction of motion of ships in a seaway. Finally, the installation of a 400 HP axial-blade propeller of the Voith-Schneider type in the bow is a continuation of what seems to be an increasing trend to provide power devices in the bow to increase maneuverability.

—from SHIPBUILDING AND SHIPPING RECORD
December 4, 1958

SHIP BEHAVIOR AT SEA

Lecture Notes on the Second Seminar on Ship Behavior at Sea held at Stevens Institute of Technology, June 1958, are now available to interested persons as ETT Report No. 708. The Seminar was sponsored jointly by the Office of Naval Research, Bureau of Ships (David Taylor Model Basin) and the Stevens Experimental Towing Tank Laboratory.

Further information on the contents of the report is available on request.

A nominal charge of Five Dollars ($5.00) per copy is being made to cover part of the cost of editing and reproduction.

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U. S. Navy Hydrographic Office

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Transportation Tech. Res. Inst., Tokyo
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Press Release 12 Jan. 1959

TETSUO NISHIYAMA

HYDRODYNAMICAL INVESTIGATION ON THE SUBMERGED HYDROFOIL PART III

THE AUTHOR

studied Naval Architecture mainly at the department of Naval Architecture of Tokyo University, Tokyo, Japan from 1944-47. After several post-graduate courses, he has become an assistant professor in the department of Mechanical Engineering of Tohoku University in Sendai. His work is connected with general hydromechanical problems in Naval Architecture, in particular with wave resistance theory and with the submerged hydrofoil.

SYMBOLS

λ	= wave length ($2\pi/K_0$).
h	= amplitude of stationary wave.
β	= phase of stationary wave.
2p or t	= chord length of a plane hydrofoil.
θ	= attack angle of a plane hydrofoil.
f	= vertical distance from the still water level to the midpoint of chord length.
$J_n(n=1,2,\ldots\ldots)$	= Bessel function of the nth order.
Y, L	= force in the y-direction, i.e. lift.
X, D	= force in the x-direction, i.e. wave resistance.
M	= moment about the midpoint of chord length.
h	= distance from the midpoint of chord length to the center of pressure.
E	= drag-lift ratio.
ρ	= density.
C	= speed of advance.
C′	= effective speed of advance.

The subscript ∞ means the corresponding value in an infinite fluid.

INTRODUCTION

IN A TANDEM type the after foil operates in the wave from the forward foil. A possibility then arises for the elimination of a substantial portion of the wave effect by selecting a foil spacing so adjusted to the design speed that the wave created by the forward foil is partially annulled by the wave from the after foil. Therefore a portion of the energy lost as wave resistance of the forward foil could be recovered by the existence of the after foil.

The object of this paper is to give a theoretical explanation for the "wave resistance recovery." Regarding the wave from the forward foil as the stationary wave, which is a progressive wave in a steady state propagating with the same speed and in the same direction as the after foil, the theoretical expression for the lift, wave resistance and moment is carried to the second order, and numerical calculations are made. Curves are given showing the variation of the characteristics with the relative position to the phase of wave, and then the optimum position of the after foil is discussed.

GENERAL EXPRESSION

Consider the two dimensional motion due to a submerged cylinder placed in stationary wave including circulation around the cylinder, the center of which is at a depth f below the mean water level. Take the origin at the center of the cylinder, with O_X horizontal and O_Y vertically upward. When the progressive waves propagate with velocity C in the positive direction of O_X, we add on the whole mass a uniform velocity of C in the negative direction of O_X; then the fluid motion becomes stationary, and the complex potential is

$$w_0=Cz+Che^{-iK_0z+i\beta-K_0f};\quad Z=x+iy;\quad K_0=g/C^2 \ldots (1)$$

The boundary condition to be satisfied at the free surface is

$$\mathrm{Re}\left|\frac{\partial^2 w}{\partial z^2}+iK_0\frac{\partial w}{\partial z}-\mu\frac{\partial w}{\partial z}\right|=0 \text{ at } z=x+if \ldots (2)$$

Then the complex potential of the disturbance by the cylinder is given in a form

$$w_1=\int_0^\infty F(K)e^{iKz}dK-\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F^*(K)e^{-iKz-2Kf}dK \quad \ldots (3)$$

where the limiting value $\mu\to 0$ is to be taken and the asterisk denotes the conjugate complex quantity.

Hence we may obtain the complex potential of the fluid motion by the cylinder in a stationary wave, that is

$$w=Cz+Che^{iK_0z+i\beta-K_0f}+\int_0^\infty F(K)e^{iKz}dK-\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F^*(K)e^{-iKz-2Kf}dK \ldots (4)$$

We transform (4) in a form

$$w=Cz+\sum_1^\infty A_n z^{-n}+\sum_1^\infty B_n z^n+\frac{i\Gamma}{2\pi}\log z \quad \ldots (4')$$

where

$$F(K)=\sum_1^\infty \frac{(-i)^n A_n}{(n-1)!}K^{n-1}-\frac{i\Gamma}{2\pi}\cdot\frac{1}{K}$$

$$B_n=Che^{-K_0f+i\beta}\frac{(-i)^n}{n!}K_0^n-\frac{(-i)^n}{n!}\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F^*(K)K^ne^{-2Kf}dK$$

Then, for the forces on the cylinder we have from the Blasius' 1st formula

$$X=2\pi\rho\,\mathrm{Im}\left[Che^{-K_0f+i\beta}F(K_0)K_0-\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F(K)F^*(K)K^2e^{-2Kf}dK\right] \ldots (5)$$

$$Y=2\pi\rho\,\mathrm{Re}\left[Che^{-K_0f+i\beta}F(K_0)K_0-\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F(K)F^*(K)K^2e^{-2Kf}dK\right] \ldots (6)$$

For the moment about the origin we have from the Blasius' 2nd formula

$$M=2\pi\rho i\,\mathrm{Im}\left[CA_1+Che^{-K_0f+i\beta}K_0\left\{K_0\frac{d}{dK_0}F(K_0)+F(K_0)\right\}\right.$$
$$\left.-\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F^*(K)\cdot K\left\{K\frac{d}{dK}F(K)+F(K)\right\}e^{-2Kf}dK\right] \ldots (7)$$

To complete the solution of the problem in any given case, we have to determine the function $F(K)$ so that the boundary condition of zero normal velocity is satisfied over the contour.

INTEGRAL EQUATION

We take the cylinder to be an ellipse, of semi-axes a′ and b′, with its major axis making the acute angle θ with the positive direction of O_X.

In terms of a complex variable $\zeta=\xi+i\eta$, we take

$$z=p\,e^{i\theta}\cosh\zeta \ldots (8)$$

and the contour is given by

$$\xi=\xi_0;\quad p\cosh\xi_0=a';\quad p\sinh\xi_0=b'$$

From (4′) and (8), we have

$$dw/d\zeta=Cpe^{i\theta}\sinh\zeta-iK_0Che^{-iK_0z+i\beta-K_0f}pe^{i\theta}\sinh\zeta+ipe^{i\theta}\sinh\zeta\int_0^\infty F(K)Ke^{iKz}dK$$
$$+ipe^{i\theta}\sinh\zeta\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F^*(K)\cdot Ke^{-iKz-2Kf}dK \quad \ldots (9)$$

Now the 3rd term in (9) is written in a suitable form in the elliptic coordinate

$$ipe^{i\theta}\sinh\zeta\int_0^\infty F(K)\cdot Ke^{iKz}dK=\frac{i\Gamma}{2\pi}-\Sigma i^n b_n e^{-n\zeta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

From (10), we get

$$iF(K)K=\frac{\Gamma}{2\pi}J_0(Kpe^{i\theta})+i\Sigma b_n J_n(Kpe^{i\theta}) \quad \ldots\ldots\ldots (11)$$

After some reduction, (9) may be reduced to

$$dw/d\zeta=\Sigma(C_n e^{n\zeta}+D_n e^{-n\zeta})+\frac{i\Gamma}{2\pi} \quad \ldots\ldots\ldots\ldots\ldots (12)$$

where

$$C_n=Che^{i\beta-K_0 f}(-i)^n nJ_n(K_0 pe^{i\theta})-(-i)^n n\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F^*(K)J_n(Kpe^{i\theta})e^{-2Kf}dK$$

$$D_n=-Ch\,e^{i\beta-K_0 f}(-i)^n nJ_n(K_0 pe^{i\theta})-i^n b_n+(-i)^n n\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F^*(K)J_n(Kpe^{i\theta})e^{-2Kf}dK$$

for $n=1$, C_1 has the additional term $\frac{1}{2}Cpe^{i\theta}$ and D_1 the additional term $-\frac{1}{2}Cp^{-i\theta}$.

The boundary condition on the contour gives

$$D_n=-e^{2n\xi_0}C_n^* \quad \ldots\ldots\ldots\ldots\ldots (13)$$

Hence from (12) and (13) we obtain

$$b_n=-Che^{i\beta-K_0 f}(-i)^n nJ_n(K_0 pe^{i\theta})+(-i)^n n\int_0^\infty \frac{K+K_0-i\mu}{K-K_0-i\mu}F^*(K)J_n(Kpe^{i\theta})e^{-2Kf}dK$$

$$+e^{2n\xi_0}\left[Che^{-i\beta-K_0 f}nJ_n(K_0 pe^{-i\theta})-n\int_0^\infty \frac{K+K_0-i\mu}{K-K_0+i\mu}F(K)J_n(Kpe^{i\theta})e^{-2Kf}dK \quad \ldots\ldots\ldots\ldots (14)\right.$$

with a similar expression for b_1, including an additional term,

$$\tfrac{1}{2}iCpe^{i\theta}-\tfrac{1}{2}iCpe^{2\xi_0}e^{-i\theta}$$

Putting (14) in (11), we have an integral equation

$$iF(K)\cdot K=\frac{\Gamma}{2\pi}J_0(Kpe^{i\theta})-\tfrac{1}{2}Cp(e^{i\theta}-e^{2\xi_0}e^{-i\theta})J_1(Kpe^{i\theta})+iChe^{-K_0 f}(e^{i\beta}H_1+e^{-i\beta}H_2)$$

$$+i\int_0^\infty \frac{v+K_0-i\mu}{v-K_0-i\mu}F^*(v)G_1e^{-2vf}dv+i\int_0^\infty \frac{v+K_0+i\mu}{v-K_0+i\mu}F(v)G_2e^{-2vf}dv \quad \ldots\ldots\ldots\ldots (15)$$

where

$$H_1=-\Sigma(-1)^n nJ_n(K_0 pe^{i\theta})J_n(Kpe^{i\theta})$$
$$H_2=\Sigma e^{2n\xi_0}nJ_n(K_0 pe^{-i\theta})J_n(Kpe^{i\theta})$$
$$G_1=\Sigma(-1)^n nJ_n(vpe^{i\theta})J_n(Kpe^{i\theta})$$
$$G_2=-\Sigma e^{2n\xi_0}nJ_n(vpe^{-i\theta})J_n(Kpe^{i\theta})$$

LIFT, WAVE RESISTANCE AND MOMENT OF A PLANE HYDROFOIL

We consider the limiting case obtained by making ξ_0 zero. The elliptic cylinder reduces to a plane hydrofoil of chord length 2p, attack angle θ, and with its midpoint at distance f from the still water level. We write

$$\Gamma=2\pi kCp\sin\theta;\quad F(K)=Cp\sin\theta\cdot f(\theta) \ldots (16)$$

then (15) is

$$f(K)\cdot K=-ikJ_0(Kpe^{i\theta})-J_1(Kpe^{i\theta})+\frac{h}{p}\operatorname{cosec}\theta\cdot e^{-K_0 f}(e^{i\beta}H_1+e^{-i\beta}H_2)$$

$$+\int_0^\infty \frac{v+K_0-i\mu}{v-K_0-i\mu}f^*(v)G_2e^{-2vf}dv+\int_0^\infty \frac{v+K_0+i\mu}{v-K_0+i\mu}f(v)G_1e^{-2vf}dv \quad \ldots\ldots\ldots (17)$$

where

$$H_1=-\Sigma(-1)^n nJ_n(K_0 pe^{i\theta})J_n(Kpe^{i\theta})$$
$$H_2=\Sigma nJ_n(K_0 pe^{-i\theta})Jn(Kpe^{i\theta})$$
$$G_1=\Sigma(-1)^n nJ_n(vpe^{i\theta})J_n(Kpe^{i\theta})$$
$$G_2=-\Sigma nJ_n(vpe^{-i\theta})J_n(Kpe^{i\theta})$$

This integral equation is of Fredholm's type of the 2nd kind and may be solved by successive substitutions.

Developing the Bessel function in (17), it is sufficient, for the present purpose, to take as the 1st approximation,

$$f(K)\cdot K=-ik-\tfrac{1}{2}Kpe^{i\theta}+\tfrac{1}{4}ik\,K^2p^2e^{2i\theta}+\frac{1}{16}K^3p^3e^{3i\theta}-\frac{1}{64}ikK^4p^4e^{4i\theta}+\cdots$$

$$-\frac{h}{p}\operatorname{cosec}\theta\cdot e^{-K_0f}\left[e^{-i\beta}\left\{\tfrac{1}{2}K_0pe^{-i\theta}\left(-\tfrac{1}{2}Kpe^{i\theta}+\frac{1}{16}K^3p^3e^{3i\theta}\right)-\tfrac{1}{4}K_0^2p^2e^{-2i\theta}\times\tfrac{1}{8}K^2p^2e^{2i\theta}\right.\right.$$

$$\left.\left.+\frac{1}{16}K_0^3p^3e^{-3i\theta}\times\tfrac{1}{2}Kpe^{i\theta}+\cdots\right\}\right.$$

$$+e^{i\beta}\left\{\tfrac{1}{2}K_0pe^{i\theta}\left(-\tfrac{1}{2}Kpe^{i\theta}+\frac{1}{16}K^3p^3e^{3i\theta}\right)+\tfrac{1}{4}K_0^2p^2e^{2i\theta}\times\tfrac{1}{8}K^2p^2e^{2i\theta}\right.$$

$$\left.\left.+\frac{1}{16}K_0^3p^3e^{3i\theta}\times\tfrac{1}{2}Kpe^{i\theta}+\cdots\right\}\right]\cdots\cdots\cdots(18)$$

Further we can develop G_1, G_2, H_1 and H_2 in a similar manner.

Putting (18) into (17) and using the relation

$$\int_0^\infty\frac{K+K_0-i\mu}{K-K_0-i\mu}K^ne^{-2Kf}dK=K_0^{n+1}(r_n-is);\ r_n=\frac{n!}{(2K_0f)^{n+1}}$$

$$+2\left\{\frac{(n-1)!}{(2K_0f)^n}+\cdots+\frac{1}{2K_0f}-e^{-2K_0f}C_1(e^{2K_0f})\right\};\ s=2\pi e^{-2K_0f}$$

we obtain as the 2nd approximation

$$f(K)\cdot K=-ik-\tfrac{1}{2}Kpe^{i\theta}B_1+\tfrac{1}{4}ikK^2p^2e^{2i\theta}B_2+\frac{1}{16}K^3p^3e^{3i\theta}B_3-\frac{1}{64}ikK^4p^4e^{4i\theta}B_4+\cdots$$

$$-\frac{h}{p}\operatorname{cosec}\theta\cdot e^{-K_0f}\left(\tfrac{1}{8}K^3p^3e^{2i\theta}Kpr_1e^{i\beta}+\tfrac{1}{8}K_0^3p^3Kpr_1e^{-i\beta}+\cdots\right)\cdots\cdots\cdots(19)$$

where

$$B_1=1-kK_0p(r_0\sin\theta+s\cos\theta)-\tfrac{1}{2}K_0^2p^2r_1+\tfrac{1}{8}kK_0^3p^3(r_2\sin3\theta+s\cos\theta)$$
$$+\tfrac{1}{4}kK_0^3p^3(r_2\sin\theta-s\cos\theta)+\cdots$$
$$B_2=1+\tfrac{1}{4}K_0^2p^2(r_1\cos2\theta-s\sin2\theta)+\cdots$$
$$B_3=1-kK_0p(r_0\sin\theta+s\cos\theta)+\cdots$$
$$B_4=1\cdots$$

Now we determine the circulation from Kutta's condition; after putting $\xi_0=0$ for the plane hydrofoil, we have

$$\frac{i\Gamma}{2\pi}+\Sigma(-1)^n(C_n-C_n^*)=0$$

hence, we have

$$k=1-\mathrm{Re}\left|\frac{h}{p}e^{-K_0f}\operatorname{cosec}\theta\cdot e^{-i\beta-i\theta}A_0^*K_0p-pe^{-i\theta}\int_0^\infty\frac{K+K_0+i\mu}{K-K_0+i\mu}f(K)KA_1^*e^{-2Kf}dK\right|\cdots(20)$$

where

$$A_0=J_0(K_0pe^{i\theta})+iJ_1(K_0pe^{i\theta})$$
$$A_1=J_0(Kpe^{i\theta})+iJ_1(Kpe^{i\theta})$$

Carrying out the integration, (20) may be reduced to

$$k=1+a_1K_0p+a_2K_0^2p^2+a_3K_0^3p^3+a_4K_0^4p^4+\text{- - -} \quad (21)$$

where

$$a_1=-(r_0\sin\theta+s\cos\theta)-\frac{h}{p}e^{-K_0f}\operatorname{cosec}\theta\cdot\cos(\theta+\beta)$$

$$a_2=-a_1(r_0\sin\theta+s\cos\theta)+\tfrac{1}{2}(s\sin2\theta-r_1\cos2\theta)-\tfrac{1}{2}r_1+\tfrac{1}{2}\frac{h}{p}e^{-K_0f}\operatorname{cosec}\theta\cdot\sin(2\theta+\beta)$$

$$a_3=-a_2(r_0\sin\theta+s\cos\theta)+\frac{a_1}{2}(s\sin2\theta-r_1\cos2\theta)+\tfrac{1}{2}r_1(r_0\sin\theta+s\cos\theta)+\tfrac{1}{2}s\cos\theta+\tfrac{1}{4}(r_2\sin3\theta+s\cos3\theta)+\tfrac{1}{4}\frac{h}{p}e^{-K_0f}\cos\theta\cos(3\theta+\beta)$$

$$a_4=-a_3(r_0\sin\theta+s\cos\theta)+\frac{a_2}{2}(s\sin2\theta-r_1\cos2\theta)+\frac{a_1}{2}r_1(r_0\sin\theta+s\cos\theta)+\tfrac{1}{2}a_1s\cos\theta-\tfrac{1}{4}(r_2\sin\theta+s\cos\theta)(r_0\sin\theta+s\cos\theta)+\frac{1}{16}(r_3\cos2\theta+s\sin2\theta)+\tfrac{1}{8}r_3+\tfrac{1}{8}(r_3\cos2\theta-s\sin2\theta)+\frac{1}{16}(r_1\cos4\theta-s\sin4\theta)-\frac{1}{16}\frac{h}{p}e^{-K_0f}\operatorname{cosec}\theta\cdot\son(4\theta+\beta)$$

Using (19) in (5) and (6), we have

$$L/L_\infty=k-K_0p\sin\theta[k^2r_0+kK_0pr_1\sin\theta+K_0^2p^2\{\tfrac{1}{2}k^2s\sin2\theta-k^2\sin\theta\cdot r_1(r_0\sin\theta+s\cos\theta)-\tfrac{1}{4}r_2\}+K_0^3p^3\{\tfrac{1}{2}kr_2(r_0\sin\theta+s\cos\theta)-\tfrac{1}{2}kr_1^2\sin\theta-\tfrac{1}{4}kr_3(\tfrac{1}{2}\sin3\theta-\sin\theta)\}+\text{- - -}]+\frac{h}{p}e^{-K_0f}K_0p[k+\tfrac{1}{2}K_0p\sin\theta-\tfrac{1}{2}K_0^2p^2\{k\sin\theta(r_0\sin\theta+s\cos\theta)+\tfrac{1}{2}k\cos2\theta\}-\tfrac{1}{4}K_0^3p^3(r_1\sin\theta+\tfrac{1}{4}\sin3\theta)+\text{- - -}]\sin\beta-\frac{h}{p}e^{-K_0f}K_0p[\tfrac{1}{2}K_0p\cos\theta-\tfrac{1}{2}K_0^2p^2\{k\cos\theta\cdot(r_0\sin\theta+s\cos\theta)+\tfrac{1}{2}k\sin2\theta\}-\tfrac{1}{4}K_0^3p^3(r_1\cos\theta-\tfrac{1}{4}\cos3\theta)+\text{- - -}]\cos\beta \quad (22)$$

$$-D/L_\infty=K_0p\sin\theta[k^2s+kK_0ps\sin\theta-K_0^2p^2\{\tfrac{1}{2}k^2r_2\sin2\theta-k^2\sin\theta\cdot s(r_0\sin\theta+s\cos\theta)-\tfrac{1}{4}s\}+K_0^3p^3\{\tfrac{1}{2}ks(r_0\sin\theta+s\cos\theta)-\tfrac{1}{2}kr_1s\sin\theta-\tfrac{1}{4}ks(\tfrac{1}{2}\sin3\theta-\sin\theta)\}+\text{- - -}]+\frac{h}{p}e^{-K_0f}K_0p[k+\tfrac{1}{2}K_0p\sin\theta-\tfrac{1}{2}K_0^2p^2\{k\sin\theta(r_0\sin\theta+s\cos\theta)+\tfrac{1}{2}k\cos2\theta\}-\tfrac{1}{4}K_0^3p^3(r_1\sin\theta-\tfrac{1}{4}\sin3\theta)+\text{- - -}]\cos\beta+\frac{h}{p}e^{-K_0f}K_0p[\tfrac{1}{2}K_0p\cos\theta-\tfrac{1}{2}K_0^2p^2\{k\cos\theta(r_0\sin\theta+s\cos\theta)+\tfrac{1}{2}k\sin2\theta\}-\tfrac{1}{4}K_0^3p^3(r_1\cos\theta-\tfrac{1}{4}\cos3\theta)+\text{- - -}]\sin\beta \quad (23)$$

And also, from (7) and (19) we have

$$M/M_\infty = 1 - K_0 p \tan\theta [k\{r_0\cos\theta - s\sin\theta + (r_0\sin\theta + s\cos\theta)\cot\theta\}$$
$$- K_0 p\{\tfrac{1}{2} r_1 \cot\theta + \tfrac{1}{4} s - k^2 (r_0\cos\theta - s\sin\theta)(r_0\sin\theta + s\cos\theta)$$
$$- \tfrac{1}{2} k^2 (r_1 \sin 2\theta + s\cos 2\theta)\} + \cdots]$$
$$+ \frac{h}{p} e^{-K_0 f} K_0 p \sec\theta [\cos\theta + k K_0 p\{\sin 2\theta - (r_0\sin\theta + s\cos\theta)\cos\theta\} + \cdots] \sin\beta$$
$$- \frac{h}{p} e^{-K_0 f} K_0 p \sec\theta [\sin\theta - k K_0 p\{\cos 2\theta + (r_0\sin\theta + s\,s\cos\theta)\sin\theta\} + \cdots] \cos\beta \ldots (24)$$

Taking a special case $h=0$ in (22), (23) and (24), we obtain the corresponding expressions of the submerged plane hydrofoil in a uniform stream.

Hence for the center of pressure we have

$$h/h_\infty = \frac{M/M_\infty}{L/L_\infty} \quad \ldots\ldots (25)$$

Now as a rough guidance for the variation of performance of a plane hydrofoil among waves, it is useful to estimate approximately the variation of drag-lift ratio, that is

$$E/E_\infty = \left(\frac{-D}{L_\infty} + E_\infty\right)\frac{L}{L_\infty} E_\infty \quad \ldots\ldots (26)$$

where E_∞ may be obtained by referring the experimental results in the wind tunnel.

NUMERICAL EXAMPLES

We take the following case as a numerical example:

attack angle $\theta=5°$, immersion $t/f=\frac{1}{2}$ $(t=2p)$

amplitude of stationary wave $2h/t=0.2$

phase of stationary wave $\beta=0$, (max. wave slope)
$\beta=\pi/2$, (zero wave slope)

The nature of stationary wave taken in this example is given in Table I.

TABLE I

λ/t	5	20	40	80	120
$2h/\lambda$	1/25	1/100	1/200	1/400	1/600
$c/\sqrt{gf}$	0.63	1.26	1.78	2.52	3.10

The variation of lift may be attributed to the variation of the effective velocity at the position of the hydrofoil and also the circulation, i.e. the effective attack angle; generally we have

$$L/L_\infty = \Gamma/\Gamma_\infty \times C'/C$$

Then in order to know the relative importance, the variation of lift and circulation is shown in Figure 1.; from which we can see that the greater part of

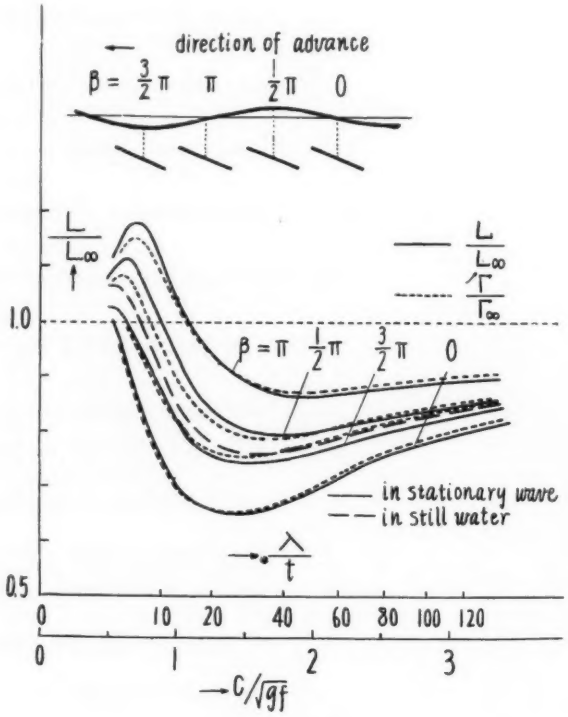

Figure 1. Lift.

the variation of lift is due to that of circulation or effective attack angle and the variation of effective velocity is very small. The former is mainly due to the variation of the direction of streamlines by wave-making among waves, and the latter increases under the crest and decreases under the hollow only by the orbital velocity of the wave.

When the phase of waves just over the hydrofoil is a crest ($\beta=\pi/2$) and midpoint from hollow to crest ($\beta=\pi$), or hollow ($\beta=3\pi/2$) and midpoint from crest to hollow ($\beta=0$), the lift is respectively larger or smaller than that in a uniform stream. However the variation of lift is considerably larger in the maximum wave slope than zero wave slope; the reason for which can be interpreted to lie in the variation of effective attack angle.

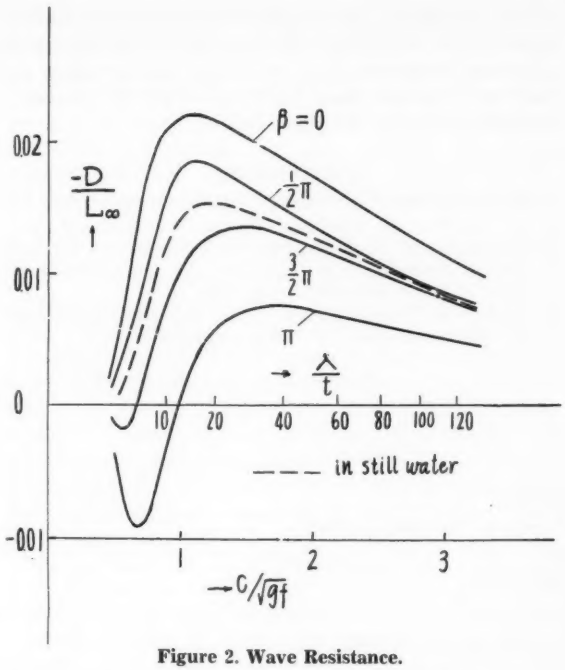

Figure 2. Wave Resistance.

Curves are given showing the variation of wave resistance due to phase of wave in Figure 2; when the phase β is $\pi/2$ and 0, or $3\pi/2$ and π, the wave resistance is respectively larger or smaller than that in a uniform stream; this comes from strengthening or annulling between the stationary wave and the wave created by the submerged hydrofoil. Hence the wave resistance recovery is maximum when the phase of the wave just over the hydrofoil is a mid-point from hollow to crest.

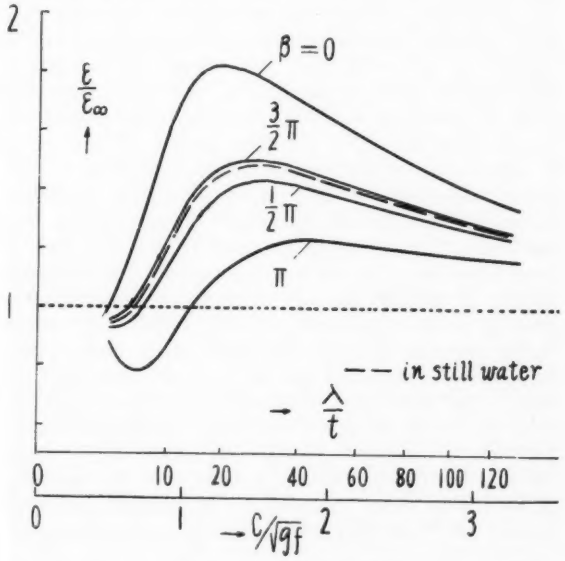

Figure 3. Drag-Lift Ratio.

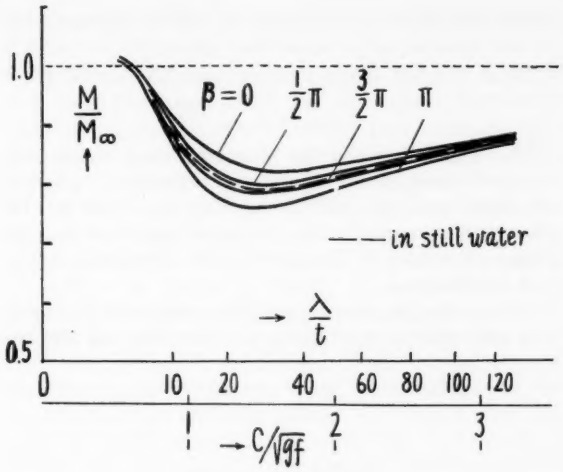

Figure 4. Moment.

Curves are given showing the performance of the hydrofoil among waves by obtaining E_∞ from the experimental results in Figure 3. The performance deteriorates under the phase $\beta=3\pi/2$, in particular too much under the phase $\beta=0$, and on the contrary improves under the phase $\beta=\pi/2$, in particular too much under the phase $\beta=\pi$.

Curves are given showing the variation of moment in Figure 4. The moment is larger under the phase $\beta=\pi/2$ and 0 or smaller under the phase $\beta=3\pi/2$ and π than that in a uniform stream. Hence the center of pressure moves to the leading edge

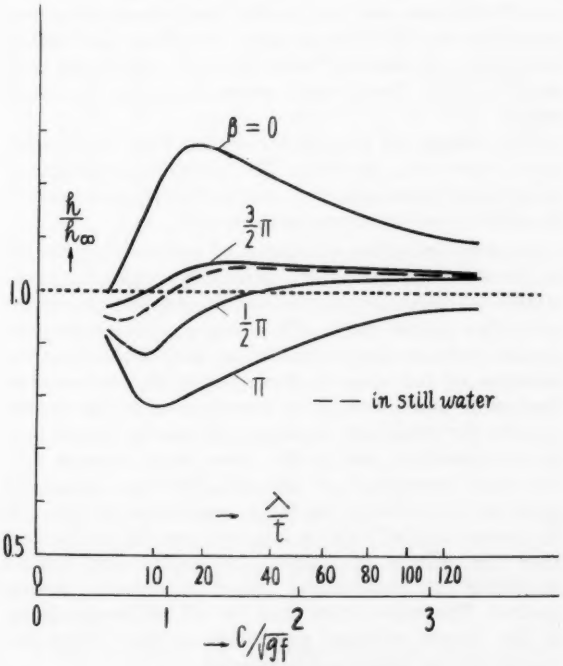

Figure 5. Center of Pressure.

under the phase $\beta=3\pi/2$ and 0, and on the contrary to the trailing edge under the phase $\beta=\pi/2$ and π, from a quarter point of chord length, as shown in Figure 5.

CONCLUSION

The expressions of the characteristics of the submerged plane hydrofoil among stationary waves are obtained and, in particular, the variation of the characteristics with the relative position to the phase of waves is clarified by the detailed numerical calculations.

When the phase of wave just over the hydrofoil is a mid-point from hollow to crest, the lift and the wave resistance are respectively larger or smaller than that in a uniform stream. Hence we can safely conclude that the after foil should be arranged under the midpoint from hollow to crest of the waves created from the forward foil.

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DISCUSSION

"Hydrodynamical Investigations on the Submerged Hydrofoil"

Part III

by Tetsuo Nishiyama

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This paper of Professor Nishiyama, the third of the series published in this JOURNAL, is a logical and important sequel to the previous studies. The problem of designing the desired lift and drag characteristics into a hydrofoil craft is an extremely complex one. This paper goes far along the path of easing the burden of design, and yet represents only a part of the theory and experiments to be developed.

The effects of separation of the foils is an eminently practical problem. The need for a directionally stable hydrofoil craft leads directly to a system involving two or more tandem foils.

It is an excellent principle of engineering to try to recover energy which ordinarily might be dissipated. As an example, the naval architect places his propellers at the stern of his ship in order to regain, in the wake, energy transferred to the water as resistance of the ship. In the case of the tandem-foil hydrofoil craft, energy is transferred to the water by the forward foil, in terms of viscous resistance, vortex shedding and in the creation of a wave system that travels aft of the foil. For most practical craft in a real fluid, the large separation of foils (in the order of 15-25 chord lengths) results in the fact that the effects of viscous resistance and vortex shedding ("downwash") have essentially disappeared. The wave train, that the aft foil responds to, is the major physical phenomenon that offers the possibility of recoverable energy.

In light of these remarks, this paper of Professor Nishiyama's becomes of great value. Here we are given guides as to the optimum separation of the foils so as to maximize lift and minimize drag.

It is stated in Professor Nishiyama's development that he derives the forces on a foil in the presence of a wave train, presumably created by some forward foil. This wave train moves with the same speed as the foil so the wave system appears as a stationary one to the foil. This is a special case of a situation which is of much significance in the design of hydrofoil craft, the stability in waves. This special case is identical to the one where the craft is operating in a following sea traveling at the same speed as the craft (the period of encounter is infinity). An extremely useful extension of the theory developed in this paper would be the calculation of forces in non-stationary waves. In this connection, it might be mentioned that a number of tests have been run of various tandem foil arrangements. In DTMB Report 1140, Leehey and Steele present some experimental and theoretical results of the motions of hydrofoil crafts with tandem vee-foils, vee-foil forward and flat foil aft, and vee-foils with a flat mid-foil. Continuations of this study are soon to begin at the University of Minnesota. In addition, a soon-to-be published report by F. Ogilvie of DTMB will present a theory of the stability of hydrofoil craft (consisting of tandem foils) in waves. Dr. Paul Kaplan, in an also soon-to-be-pub-

* Although we failed to include a credit line, the discussion on Part II in the November 1958 issue, was also written by Dr. Silverstein.

lished report by the Experimental Towing Tank, indicates that Ogilvie's theory should be modified, in order to take into account the effect of the waves, created by the forward foil, on the aft foil. These studies, dictated by the important practical problem of stability, indicate another avenue of needed theoretical work. I would strongly suggest that Professor Nishiyama, or some other investigator having the theoretical bent, investigate the forces developed by a vee-foil; that is, a surface-piercing foil. The sequence of problems attacked by Professor Nishiyama is appropriate: 1) the determination of the hydrodynamic characteristics of the surface-piercing foil, 2) the inverse problem—determination of the profile from a prescribed pressure distribution and 3) the determination of the hydrodynamic characteristics of the after foil as affected by the waves created by the forward foil. As step 4), as suggested earlier, the forces and moments of a foil operating in a progressive wave system would be of great value.

In a discussion of a theoretical paper like this one, it is useful to condense the author's procedure, along with various comments.

Prof. Nishiyama initially considers a cylinder in a stationary wave train (zero relative speed). The long axis of the cylinder is perpendicular to the direction of motion. There is a circulation, Γ, around the cylinder (a lift force is developed). The two-dimensional velocity potential is developed, satisfying the free-surface condition (equation (2))—the free surface is a streamline. The complex velocity potential is then expressed in terms of the unknown function, $F(K)$, and the circulation, Γ. Using the Blasius' formulas, given in complete form in my discussion of Prof. Nishiyama's first paper, published in the August 1958 JOURNAL, the expressions for lift and moment are given by equations (5), (6) and (7). At this point, a special cylinder is considered, that is, one whose cross-section (taken at an angle Θ to the direction of motion) is an ellipse. Elliptical coordinates are used to express the equation of the cylinder and the derivative of the velocity potential (which yields the velocity in the direction of the derivative). The normal velocity on the perimeter of the elliptic cross-section must be zero. This condition (equation 13), sets up an integral equation in Γ and $F(K)$.

As an approximation to a hydrofoil, the minor axis is set equal to zero; the result is a two-dimensional flat plate, of chord equal to 2p, and at an angle of attack, Θ. The result is then a somewhat simplified form of the previous integral equation. A second order approximation to the solution of this equation is obtained by an iteration process. The Kutta condition, the velocity at the trailing edge is zero, then yields a solution for the circulation. The now determined form of the function $F(K)$ is inserted into the Blasius' equations for force and moment and the result is equations (22), (23), and (24) for lift, drag and moment of the flat plate at an angle of attack in a stationary wave train.

It should be noted that the forces and moments are non-dimensionalized by equivalent forces and moments in an infinite fluid (no free surface), with the exception of drag, which is non-dimensionalized by the lift force. This served to emphasize one of the basic assumptions of this development; this theory assumes a perfect fluid (zero viscosity). In the case of a two-dimensional foil at an angle of attack in an inviscid infinite fluid, there is a lift force, but no drag (D'Alembert's paradox). D/D_∞ would be equal to ∞ as $D_\infty = 0$. D itself is not equal to zero, as even in an inviscid fluid, the presence of the free surface causes a drag force due to the creation of waves that are carried to infinity. The concept of symmetry aids in resolving, intuitively at least, this paradox. In the infinite fluid, the conditions far ahead and far astern of the two-dimensional foil are identical; no energy has been lost. However, in the case involving the free surface, there are no waves far ahead but there are waves far astern; this asymmetry shows that energy has been transferred from the foil to the water.

The numerical examples developed by the author are extremely interesting. When the center of the foil is midway between the crest and the trough of the waves, the lift is at a maximum and is greater than the case of the foil traveling in undisturbed water (see Figure 1). It may also be noted that Professor Nishiyama has also plotted the circulation. This clarifies the picture in that it shows that the major effect on lift is the change in circulation and not the orbital velocity of the wave. In Figure 2, we see that the drag, in this optimum position for lift, is actually reduced. At some low values of the Froude number based on submergence ($C/\sqrt{gf}$), there exists a thrust on the foil instead of a drag. This appears truly to be almost "something for nothing."

The more exciting result, from the designer's point of view, is the wedding of Figures 1 and 2 into Figure 3, the drag-lift ratio. The inverse of this ratio, lift/drag, is one of the usual criteria of good design of a hydrofoil craft. A great deal of care is exercised to maximize lift/drag. Figure 3 shows clearly (and this has been borne out by experiment) that considerable improvements in lift/drag are possible by a proper selection of foil separation.

It is worth mentioning that Professor Nishiyama has considered the foil acting in a wave train. The properties of these waves, as related to the foil causing them, is not presented. The wave properties, however, are readily developable from extensions of Professor Nishiyama's paper in the August 1958 JOURNAL, or from other theories of the flat plate hydrofoil.

Unfortunately, all the experimental data I have seen have been classified, as a security measure. These data, however, are derived from unsystematic

test programs; usually these tests are of the foils of a specific hydrofoil craft and the tests were not guided by any firmly developed theory. It is therefore reasonable to suggest that the theory developed in this paper should be confirmed by systematic model testing. Further investigations into a more general theory is also warranted. As mentioned earlier, the properties of surface-piercing foils is an important and practical problem. The effect of section shape and finite aspect ratio deserve attention.

In summing up the results of this trilogy of papers by Professor Nishiyama for the JOURNAL, I would say that they represent an important contribution to hydrofoil theory. These papers present an excellent example of the value of theoretical studies. To the mathematician, these extremely difficult hydrodynamic problems require ingenuity and a thorough knowledge of his mathematical tools. Mathematical prowess is amply demonstrated by a successful solution of these complicated problems. In addition, the solutions clearly indicate a so-called iterative process of the development of an all encompassing theory. The mathematician first sets up the simplest possible problem that still contains the physical concepts. When this is solved, he adds a few more complicating refinements and uses his first solution as a guide, and so on.

It is the designer, however, who gets the most. He may skim off the cream of the theoretical investigations, using the results to great advantage, without the need for complete understanding of the process of developing the theory. With the theory in hand, the designer need only ensure that a few experiments are run, confirming the theory. Then, with a good measure of confidence, he may design his system, knowing which are the important parameters and the effect of varying these parameters. He is no longer hobbled to the need of running exhaustive model tests of his particular configurations. Therefore, it is clear that the theoretician is extremely valuable to the engineer. Papers such as these are of great importance to the practical man.

A survey of the subject of fatigue in marine engineering has been recently published by B. K. Batten, titled "An Introduction to Fatigue in Marine Engineering." The article, well illustrated with examples of service fatigue failures, covers basic considerations of fatigue failure and common types of failures observed in marine application. Included are discussions of failure in crankshafts, line shafting, tail shafts, bolted assemblies, turbine blades, and other examples. Methods of detection are discussed, covering the magnetic particle method, fluid penetration method, etching, radiographing, use of pressure sensitive tape and ultrasonic methods. Design considerations for avoiding conditions conducive to fatigue attack are covered briefly. The article is a valuable summary of the subject for all marine engineers who do not require a detailed and comprehensive knowledge.

—from INSTITUTE OF MARINE ENGINEERING
November, 1958

"TRANSACTIONS OF THE INSTITUTE OF MARINE ENGINEERS"

THE USE OF HIGH PRESSURE STEAM IN MARINE INSTALLATIONS

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INTRODUCTION

THERE IS A widespread tendency to classify steam machinery installations in relation to the initial steam pressure and temperature adopted in each case. Thus an installation utilizing a higher steam pressure tends to be regarded as being more "advanced" than one employing a lower pressure. This is a far from satisfactory generalization and many other facets of the installation design must also be considered. In fact, it is quite possible in practice for a higher pressure installation to be less economic, in the overall sense, than a lower pressure installation, particularly in respect to marine mobile power plants.

The application of high pressure steam to marine installations has never been on anything more than a sporadic and limited basis. Steam temperatures on the other hand have advanced steadily over the years. It is the purpose of this paper to examine some of the reasons which restrict the advance to higher pressures for marine purposes.

GENERAL TRENDS

Figure 1 indicates the general trends of pressures and temperatures for both land and marine applications during the last two decades. The land power station data shown are indicative of British practice for the largest units. Similar data for U.S.A. public utilities, generally speaking, would be several years ahead in time of the British practice and a further advance to supercritical stations with steam conditions 4,500 p.s.i., 1,150° F reheated to 1,050° F and 1,000° F is currently underway.

When comparing these land and marine trends

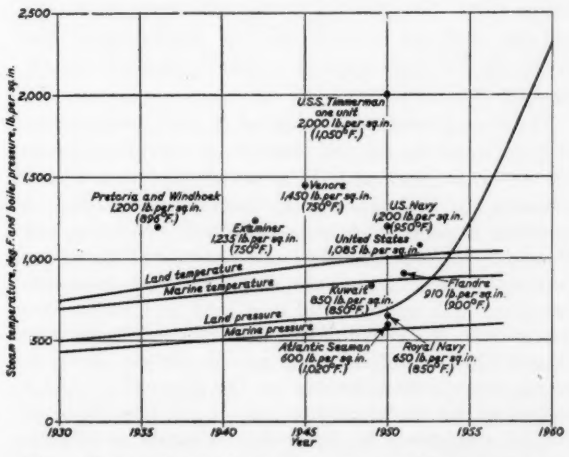


Figure 1. Trends of steam pressures and temperatures.

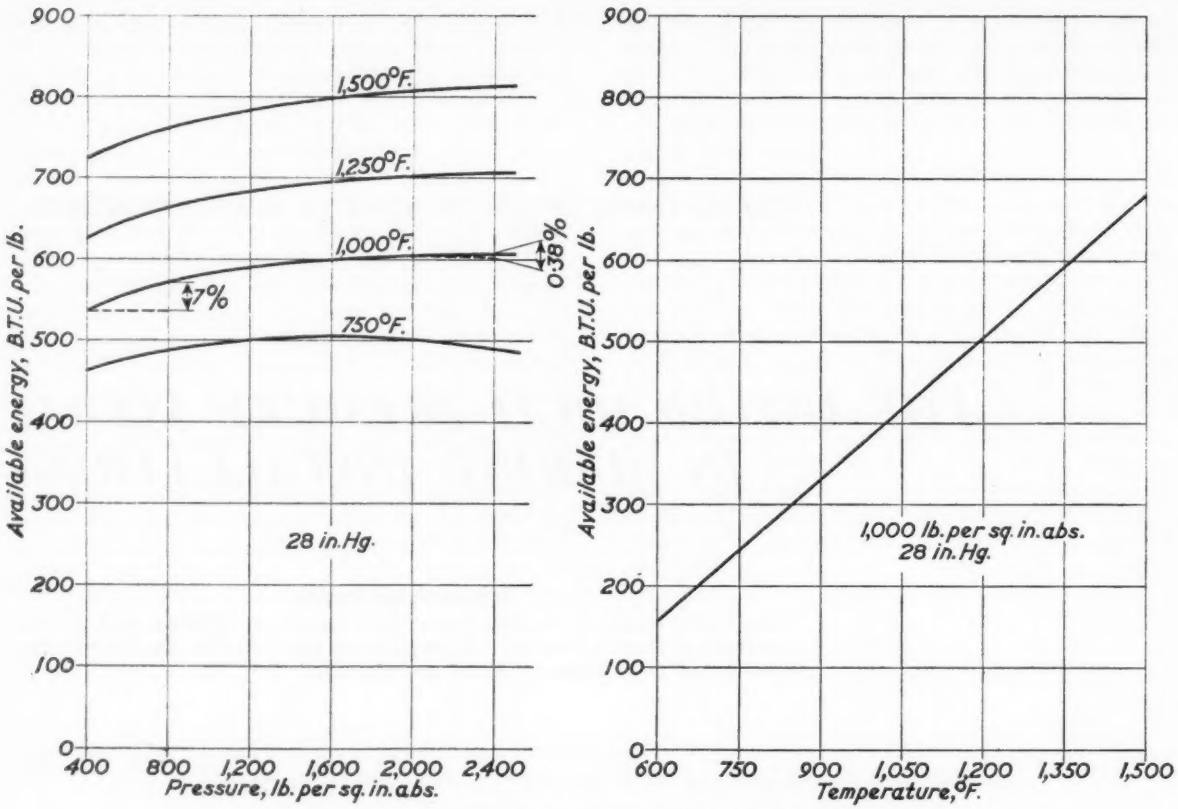


Figure 2. Effect of initial pressure and temperature on ideal adiabatic heat drop.

it must be recognized that the initial pressure is a function of the unit size. In modern British power station practice 900 p.s.i. is currently used for sets of 60 MW output, 1,500 p.s.i. for 100 MW and 2,400 p.s.i. for 200 MW.

Figure 1 shows that very occasionally a marine plant has been designed for pressures significantly higher than the general trend but these cases are isolated and the overall service performance has evidently not been such as to justify shipowners repeating such designs.

The steam conditions adopted at any given period of time must be related strictly to overall economics. In this connection it is necessary to evaluate efficiency or fuel rate for the installation in relation to other aspects such as reliability, weight, space, first cost, ease of operation, competence of operating personnel and maintenance costs. Such an economic yardstick will apply equally to land and marine installations: the reason why marine development is almost always behind land power station development—even after allowing for the generally smaller output of the marine plant—can in the first place be largely explained by the more arduous conditions under which the marine plant must operate. In particular, marine installations must withstand the continuous effects of:—

Running astern and rapid maneuvering
Rolling and pitching
Flexible foundations
Vibration

together with the possibility of grounding and collision. Further, it is necessary to avoid rotor critical speeds below the maximum speed, which often leads to large diameter rotors with consequent high interstage gland leakage. While the choice of design speed for a power station turbine is restricted by the frequency of the electricity supply system, such a machine can satisfactorily operate above the first critical speed.

It can be expected, of course, that economic pressure will always be forcing technical advance to its practical limits and it is therefore of interest to examine additional reasons for aiming at a lower level of steam pressure in marine installations than for land installations.

THERMODYNAMIC CONSIDERATIONS

Figure 2 illustrates the energy available in steam when expanding from various pressures and temperatures down to an absolute pressure, correspond-

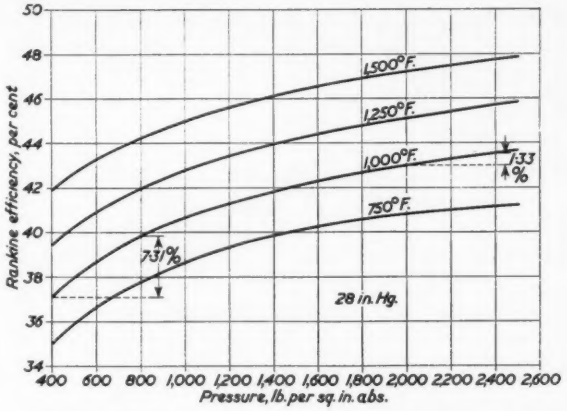


Figure 3. Effect of initial pressure and temperature on Rankine efficiency.

ing to 28-in. Hg. vacuum. The curves show that this energy available to perform work in the engine increases with the initial pressure and temperature and will also increase with vacuum. The gain in available energy is more marked at the lower pressures than above, say, 1,200 p.s.i. On the other hand, the gain due to increasing the initial steam temperature is almost in direct proportion to the increase in temperature.

In Figure 3 the effects of initial steam pressure and temperature on the theoretical efficiency of the cycle are examined. Rankine cycle efficiencies (that is, assuming the machinery to be 100 per cent efficient) are plotted against varying initial pressures with the vacuum maintained constant at 28-in. Hg. Temperature curves span the range between 750° F and 1,500° F. It will be noted that approximately equal gains in efficiency result from increasing the temperature in equal increments, but that this is not the case with equal increments of pressure.

The Rankine efficiencies shown in Figure 3 are decreased in the practical case by introducing the boiler and turbine efficiencies and subtracting an amount equivalent to the percentage of heat supplied to the propulsion auxiliary machinery and other services such as turbo-generators. Of these factors it is the turbine efficiency which will be significantly modified by changes in the initial steam conditions and the turbine speed and size are important parameters in relation to the steam conditions selected.

The losses in a turbine may be subdivided into:—

(i) Leaving loss
(ii) Leakage through glands
(iii) Losses in blading
(iv) Windage and disc friction
(v) Wetness loss
(vi) Mechanical loss
(vii) Radiation

All these losses are governed to a greater or smaller extent by the initial steam conditions. The losses in blading are particularly sensitive to initial steam pressure and increase rapidly with increasing pressure, due either to the smaller inlet end blade height or to the additional loss resulting from partial admission.

TURBINE ASPECTS

Increasing the initial steam pressure will have a profound effect upon the turbine gland problem and the difficulties of maintaining gland leakage within reasonable proportions are greatly increased.

Figure 4 illustrates typical arrangements for marine turbines designed for 650 p.s.i. 850° F, and 1,450 p.s.i. 950° F, respectively. The substantial increase in shaft gland sealing associated with the high pressure severely reduces the number of blading stages that can be accommodated in the h.p. cylinder as compared with the lower pressure installation.

However, far from being suited to a reduction in the number of blading stages, the increase in heat drop available with increased initial conditions calls in general for more blading stages (or for an increase in speed) to maintain reasonable blade/steam velocity ratios. One solution to this problem is to increase the number of turbine cylinders by using a three-turbine instead of a two-turbine design. The turbine rotor shown in the bottom half of Figure 4 is representative of a h.p. rotor of a three-turbine design. Three turbines, i.e. h.p., i.p., and l.p., lead inevitably to increased mechanical losses, extra complication and increased first cost.

Efficiencies of high pressure stages will be decreased with increase in pressure since the decrease in specific volume of the steam leads to shorter blades and smaller nozzles which are relatively inefficient.

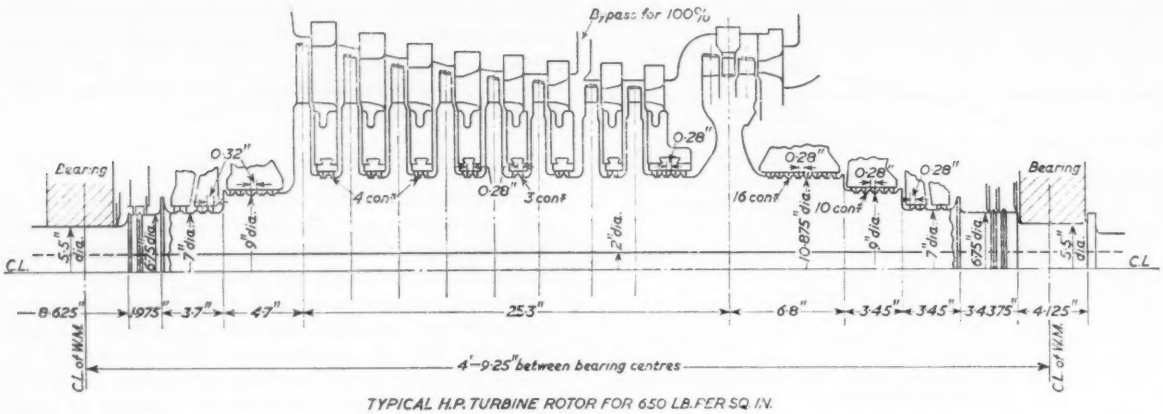
If the initial pressure is high compared with the initial temperature, the moisture content in the exhaust blading may be excessive from the blade erosion aspect, and in any event the moisture loss associated with high pressures will give rise to a small reduction in turbine efficiency.

As will be seen from Figure 5, all these effects combine to reduce the practical gains associated with increasing pressure to about one-third of the theoretical values illustrated in Figure 3.

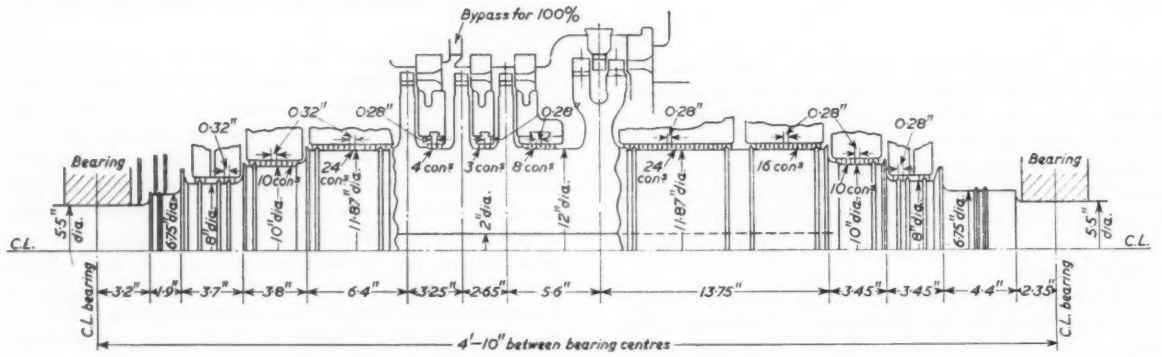
It follows, therefore, that the application of high pressures to turbine installations must be executed with great care so as to ensure that the relatively small gains in efficiency can be achieved in practice. Further, these gains can introduce penalties in first cost, weight and maintenance.

STEAM PRESSURE VERSUS INSTALLATION WEIGHT

The weight aspect can best be illustrated by reference to the results of a detailed investigation which has been carried out to establish the optimum pressure level for a high powered installation operating at a superheater outlet temperature of 950° F.



TYPICAL H.P. TURBINE ROTOR FOR 650 LB. PER SQ. IN.



TYPICAL H.P. TURBINE ROTOR FOR 1,450 LB. PER SQ. IN.

Figure 4. Typical h.p. turbine rotors.

Figure 5 indicates the effect of variations in the initial steam pressure upon boiler weight, total machinery weight, overall fuel consumption, and finally upon the range of the vessel. In computing the curve showing the effect upon the range of the vessel it has been assumed that the total weight of machinery and fuel is maintained constant; i.e. as the machinery weight increases with higher pressures, the fuel carried must be correspondingly reduced.

The conclusions to be drawn from the analysis of this typical installation are: —

(i) *Weight and space*

Increments in steam pressure above 500 p.s.i. result in significant increments in the weight of the machinery installation. Variation of space requirements with pressure level is negligible.

(ii) *Performance*

Increments in steam pressure above 400 p.s.i. result in gradually diminishing reductions in overall fuel consumption rates.

(iii) *Wetness*

The state of the steam entering the main condenser under any condition of operation imposes no restriction on the choice of any initial pressure between 400 and 1,200 p.s.i. when the initial temperature is 950° F.

(iv) *Range*

For most types of vessel there is a rapid initial increase in range with increase in pressure above 400 p.s.i. Increments of pressure above about 700 p.s.i., however, have only a minor effect on range. For the particular installation considered the maximum improvement in range (3½ per cent) has been obtained at a little over 800 p.s.i.

(v) *Reliability*

Reliability, in general, is likely to be adversely affected by increase in steam pressure and greater care and skill must be exercised in the design and workmanship associated with the production and refitting of all items affected by the pressure level.

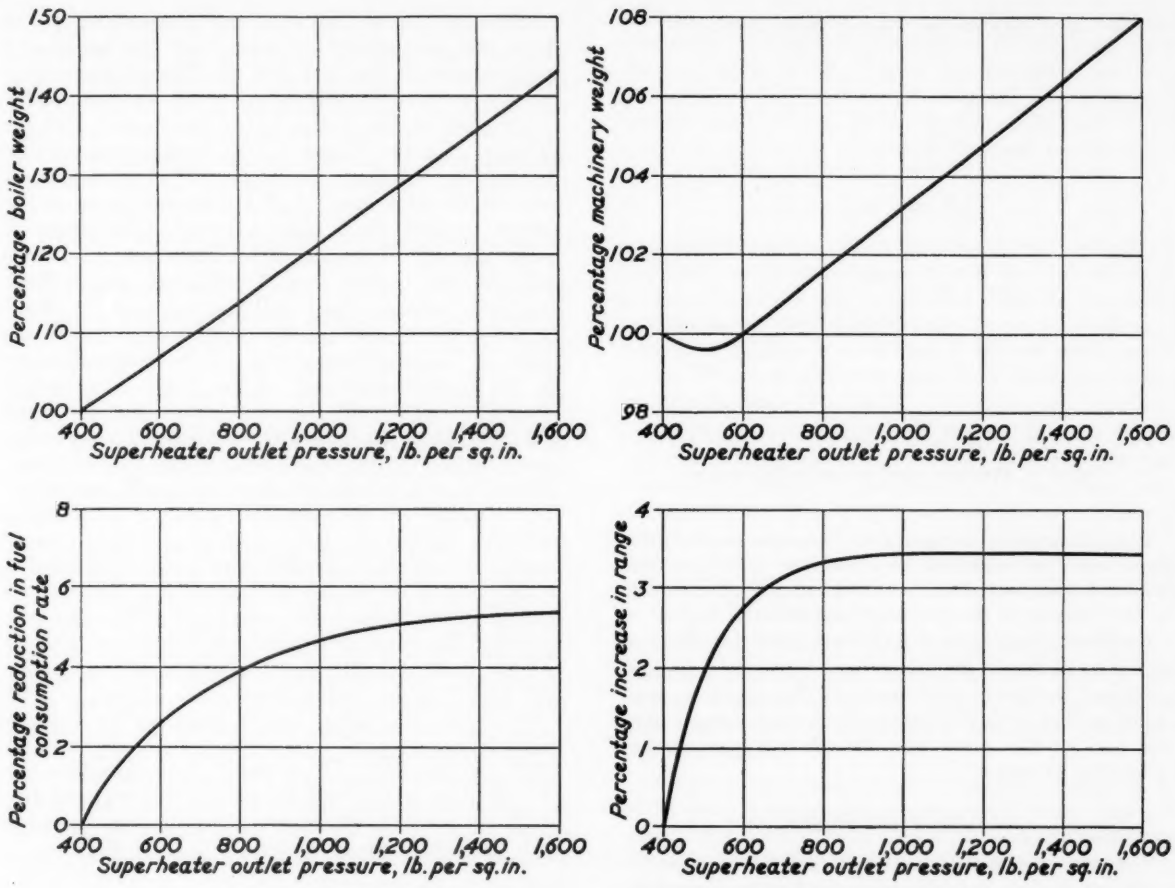


Figure 5. Effect of initial steam pressure on machinery weight and performance.

(vi) *Operation*

The optimum steam pressure level is not influenced by considerations of operation, except for more elaborate feed water treatment required at the higher pressures.

(vii) *Maintenance*

Every increment in the steam pressure level will be accompanied by increased maintenance of all items of which the operating conditions are related to the steam pressure.

It will be evident that considerations of weight are of no real significance to land power station installations. In the case of base load machines the yearly fuel consumption constitutes a large proportion of the operating costs and there is a sound economic reason for going to the small gains in efficiency offered by increases in initial pressure and accepting the penalties of weight and the necessity for a high standard of maintenance.

It is equally clear that these same considerations do not necessarily apply to marine installations.

HIGH PRESSURE LAND STATION

An outstanding example of a modern high pressure land installation is represented by the latest power plant addition to the Philo Power Station in Ohio. The steam conditions are 4,500 p.s.i., 1,150° F, reheated to 1,050° F and again to 1,000° F. The boiler, which works on the forced circulation once-through principle, is connected to four-cylinder turbine machinery by steam pipes having 4½-in. bores and 7¾-in. outside diameters. The h.p. turbine shell is of spherical shape and is cooled by steam at 4,500 p.s.i., 950° F. A very high demineralization standard for the feed water is specified; for example, the iron content of the feed water must not exceed 0.01 p.p.m. The designed net overall efficiency of the plant is 40 per cent.

PRESENT PHILOSOPHY

The stage in the development of marine steam turbine installations for the larger ships has thus been arrived at, where the generally accepted practice is to use the highest permissible temperature and associate this with a modest pressure.

The Use of High Pressure Steam in Marine Installations

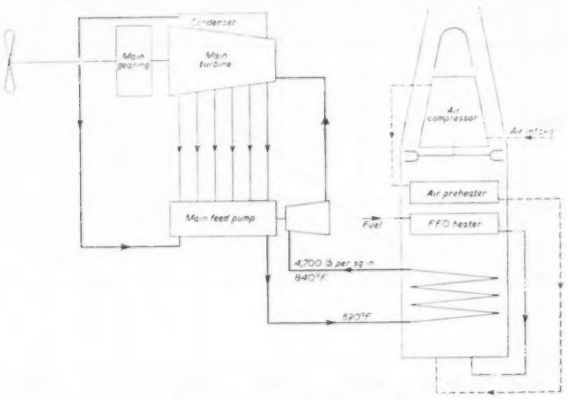


Figure 6. Pressure combustion boiler cycles.

It is of interest to speculate whether or not this trend can be expected to continue. It is possible that the situation may be modified to some extent by the advent of the pressure combustion boiler.

Reference to Figure 5 will show that the effect of increases of steam pressure upon the weight of conventional boilers is very marked. The pressure fired boiler promises to eliminate this severe weight penalty and at the same time to effect a remarkable reduction in space.

PRESSURE FIRED BOILERS

The use of a gas turbine to supercharge a boiler combustion chamber is not new; it has been exploited in the Velox boiler for many years. However, the rapid development of gas turbines in recent years has introduced a distinct possibility of some substantial advances in boiler and power installation design.

Figure 6 indicates two basic approaches to the design of a pressure combustion boiler.

In Scheme A the gas turbine is required to produce just sufficient power to compress the combustion air, and in consequence the pressurized gas to be extracted from the boiler to drive the gas turbine need not exceed the modest temperature of 850° F or thereabouts. The exhaust from the gas turbine may be used for feed water heating before passing to the funnel. Design studies for such a scheme indicate that:—

(i) Boiler weight and size can be drastically reduced, possibly down to 50 per cent compared with conventional boilers.

(ii) The combustion air system required with conventional boilers is eliminated, of course.

(iii) The boiler may be started more quickly.

Scheme B takes the development a stage further and provides for the gas turbine developing power much in excess of that required to compress the combustion air. In this case the pressurized gas to drive the gas turbine is drawn from the boiler at a temperature of up ot 1,450° F. The exhaust from the gas turbine is once again used for feed water heating before being directed to the funnel. The gas turbine is in two stages with a free power turbine driving an auxiliary generator. This arrangement permits the maintenance of a constant speed of the power turbine shaft over a fairly wide range of boiler output. Depending upon the steam conditions and the gas turbine cycle employed, gas turbine auxiliary power output will represent up to about 15 per cent of the power generated in the main plant. If this auxiliary power can be used effectively, the overall efficiency of the cycle may be improved by up to 10 per cent, since the auxiliary power is being generated at an efficiency closely approximating to the boiler efficiency. The ultimate reliability of this type of boiler plant will depend on the outcome of development work in connection with the control of corrosion arising from the presence of vanadium and sulphur in the fuel oil burned in the boilers. Problems associated with the overall control of the boiler over wide and rapidly changing outputs also require further consideration. Nevertheless, it is probable that the pressure fired boiler will take its place in the foreseeable future.

The optimum initial steam pressure for marine installations may then be expected to rise towards 1,200 p.s.i. since the boiler weight and therefore the overall plant weight will be much less penalized due to an increase in steam pressure than is the case with the conventional boilers.

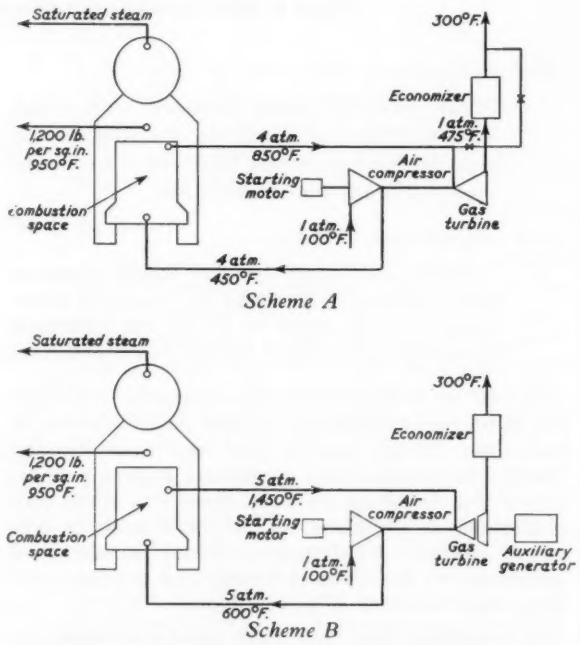


Figure 7. High pressure/low temperature cycle.

CONTINENTAL CONCEPTS

It may also be of interest to refer back to proposals which came out of Germany at the end of World War II, which tend to modify the philosophy governing the present general trend of development in so far as they associated the highest possible pressure with a modest temperature and achieved remarkable low weight characteristics.

Figure 7 illustrates the German proposition which was under active development as a possible lightweight prime mover for super-aircraft. This idea, of course, is not new and has appeared in one form or another in Britain, the United States and Germany during the last twenty years. The pressure fired boiler is designed with small bore tubes on the once-through principle and generates steam at 4,750 p.s.i. and 840° F. The fuel passes from the fuel tank through a fuel oil heater located in the gas circuit of the boiler and then to the combustion chamber.

The steam generated in the boiler is led to the feed pump turbine and then to the main power turbine. Both turbines are of the multi-stage type. Of the steam entering the main turbine a high proportion is drawn off to perform a multi-stage feed heating process for the feed water before it passes back into the boiler. This is done by injecting the bled steam into an appropriate stage of the feed pump and thus achieves direct contact feed heating within the feed pump itself. The condenser is designed to operate at a convenient sub-atmospheric pressure, and the extracted feed water is passed back to the feed pump suction. The overall efficiency obtainable with this type of plant is competitive with good modern practice and the weight achieved in the German prototype installation bettered conventional plant by a very significant margin.

This plant is not being described here as a serious contender for marine installations in the foreseeable future but it is sobering to contemplate that such a steam cycle has been developed and prototype plants actually run which significantly modify the present conception of optimum steam conditions.

THE FUTURE

What of the future? In the first place it is unlikely that any spectacular changes will be seen as far as steam pressures are concerned. This is not to be construed as implying that the correct selection of pressure in any installation is not of vital importance. Success, however, cannot be judged in terms of up and up.

Pressure is a dependent rather than a fundamental design parameter. Overall economics will dictate the degree of complexity of the steam cycle in relation to cost, weight, maintenance, number of operating personnel, etc. Then the steam temperature can be decided and the pressure level optimized. The important criterion is then not how high is it, but how "right."

This much can probably be prophesied safely. If pressure fired boilers have time for development before being overtaken by the nuclear age, the general trend in steam pressure will take a decisive upward trend.

For nuclear installations the present state of development necessitates steam plants with very low steam conditions, reverting almost to the beginning of steam plant development. However, this is very definitely an interim phase and it will probably not be too long before nuclear technology will be equal to providing steam with initial conditions right up to the required modern standard.

Small gas turbines play a vital part in rocket design. Practically universally used in all liquid-fueled missiles and rockets as fuel pumps, they have also found application for other functions, such as supplying power for coolant pumps, hydraulic control system pumps, and small electrical generators. A paper presented to A.S.M.E. by O. E. Lancaster and C. J. Bates in December summarized the various types in most common use and their features.

Ranging in rotor size from two to twenty inches, and in power from 1 to 15,000 HP, such turbines turn up to 100,000 RPM. Three basic types of engines may be identified. The "bleed" unit is powered with propellant gases which are piped from the main combustion chamber of the missile. They are expanded to ambient conditions through the turbine. The "topping" unit has its own combustion chamber, from which the gases expand through the turbine and are then dumped into the main combustion chamber. In the "separate gas-generator" type, gases are similarly supplied from a separate combustion chamber, but are expanded to ambient conditions, completely by-passing the main combustion chamber. A fourth type, a blast turbine, operating directly in the main propellant gas stream, has not been successful.

Impulse turbines are used almost exclusively because of their low weight per horsepower and their simplicity. Efficiency, which depends on high rotor speeds, is often sacrificed to avoid cavitation in fuel pumps and in some cases to obtain increased reliability. Fuels are diversified, the most popular type being hydrogen peroxide. LOX with kerosene, alcohol, JP4, and other such fuels are also extensively used.

Usual required life is one to five minutes, though some units may be expected to perform as long as fifteen minutes. A designed life of about one hour, including test time, is therefore sufficient for most of these small prime movers.

—from GAS TURBINE PROGRESS REPORT, 1958
American Society of Mechanical Engineers

RUDOLPH MICHEL

A QUARTER CENTURY OF PROPULSION SHAFTING DESIGN PRACTICE AND OPERATING EXPERIENCE IN THE U. S. NAVY

THE AUTHOR

received his B.S. and M.S. degrees in Mechanical Engineering from the University of Wisconsin and University of Illinois, respectively. After an extensive experience in industry and teaching at Virginia Polytechnic Institute and the University of Illinois, he entered Government service, where he was employed for almost 26 years. The greater part of this service was with the Machinery Design Section of the Bureau of Ships, where he became head civilian engineer of the Machinery Scientific and Performance Section and later Consulting Engineer. He retired from the Bureau of Ships in April, 1958 to accept a position as Senior Project Engineer with ACF Industries, Nuclear Products Division in Washington, D.C. He has been a frequent contributor to this and other technical magazines.

INTRODUCTION

MUCH has been done in the last quarter century to improve the design and the manufacture of propulsion shafting. It is the purpose of this paper to review progress in design methods and to present operating experiences on ships of the U.S. Navy during this period. The design of Navy shafting is governed by General Specifications for Ships and the Design Data Sheets for Propulsion Shafting, reference 3, which are reissued as progress is made.

The most significant changes made in design have resulted from operating experiences and our increased knowledge of dealing with problems of vibration and corrosion. Great progress has been made during the past 25 years in the methods of computing vibratory stresses and frequencies of the shafting and connected masses. The development of instruments for making vibration measurements has contributed greatly to this progress. Significant contributions have been made in the field of corrosion protection.

OPERATING EXPERIENCES

Shaft failures on vessels of the U.S. Navy during the last 25 years may be classified according to the cause of failure, as follows:

a. Fatigue.
b. Combination of fatigue and impact.
c. Torsional vibration.
d. Fretting corrosion.
e. Electrolytic corrosion.

The writer does not know of any case where shaft failure resulted solely from impact caused by the propeller striking a submerged object. The icebreaker USS *Edisto* had two shaft failures, one in 1949, the other in 1956. The shaft which failed in 1949 was a moly-vanadium steel of 0.41C, with a tensile strength of 83,000 p.s.i. and a yield strength (0.2 per cent offset) of 49,800 p.s.i. Brinell hardness was 160 and elongation 30 per cent in 2 inches. The failure occurred while the ship was engaged in icebreaking operations in water at about 28° F. At this temperature, energy absorption as determined

from Charpy impact tests is low. Fracture started in a keyway about 3 inches inside the end of the propeller hub. No mention was made of corrosion resulting from leakage of water into the keyway. Characteristic fatigue markings, showing progressive failure, were present. Since much of the evidence was lost, an absolutely definite determination of the cause could not be made. There is a possibility that an initial fatigue crack, starting at a point of stress concentration at the keyway fillet, served as a notch for failure by impact. The final report of the 1956 shaft failure of the *Edisto* has not yet been received.

Figure 1 shows a shaft failure due to torsional vibration. The shaft in question was from the

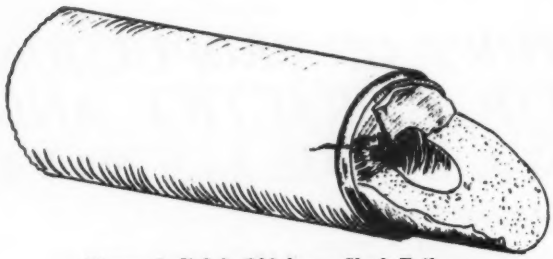


Figure 1. *U.S.S. Oklahoma* Shaft Failure.

USS *Oklahoma*, driven by a 4 cylinder reciprocating steam engine. A dangerous torsional critical frequency occurred near full power speed on this ship. The failure took place at a stress concentration point near the outboard coupling. The latter had been modified to eliminate this defect a short time prior to loss of the ship at Pearl Harbor.

The Navy has had one case of shaft failure, due to fretting corrosion. This involved an alloy No. 4 shaft on which was mounted a manganese bronze propeller. The failed section is shown in Figure 2. Failure apparently started a few inches aft of the forward face of the propeller hub, perhaps at the keyway edge. The characteristic oyster shell rings, indicative of progressive failure, are in evidence. Also, there is evidence of copper penetration on the surface of the failed section. After the effective shaft section had been reduced by fatigue cracks, the remainder failed in shear. The ship had just completed a 4 hour full-power run and was still

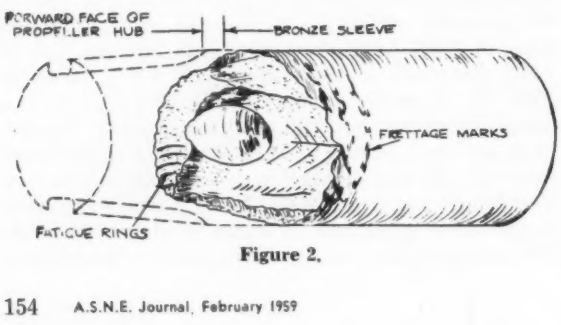


Figure 2.

making 99 per cent of full power when the failure occurred. The shaft had been in service about 18 months and had made about 3.25 million revolutions up to the time of failure. Bending stress on the shaft, due to gravity alone, was 4400 p.s.i. Due to off-center thrust, it is estimated that this stress was doubled, thereby equaling 8800 p.s.i. During a high speed turn, the torsional stress in the shaft will be increased by about 25 per cent of the full power stress. This condition of course, does not prevail very often and is of short duration, about 2 minutes, when it does.

By far the greater number of replacements of shafts on Navy ships have been caused by electrolytic corrosion fatigue which has occurred in shafting of all types of vessels where the shafts have not been completely protected from salt water by continuous bronze sleeves or rubber covering. Up until 1949 it was customary to protect stern tube shafting with rubber and intermediate and propeller shaft with paint, excepting in the areas adjacent to bronze sleeves. Adjacent to the sleeves, it was customary to apply steel rings, Figure 3, which would corrode if not painted. These were renewed

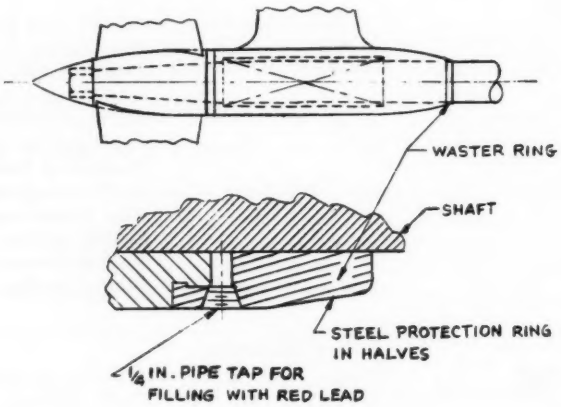


Figure 3. Waster Ring.

periodically. However, cracks invariably occurred in the shaft near the end of and underneath the steel waster rings. The rings were welded or shrunk on the shaft. In December 1949, the Bureau of Ships issued an order to all Navy activities to chip back the steel protector rings ¼ inch at the end of the bearing sleeve and examine the shaft for cracks. Cracks up to ⅛ inch deep for 10 inch shafts and ¼ inch for shafts over 10 inches diameter are obliterated by grinding after removal of rings. Deeper cracks are welded. In either case, synthetic rubber covering is applied after removal of the steel waster rings.

The Pacific Northwest Section of the Society of Naval Architects and Marine Engineers held a symposium on tail shaft failures in November 1954. Mr.

J. F. Mills, head of the Material Laboratory of the Puget Sound Naval Shipyard, reported the following data in regard to propeller shafts of vessels docked during the ten year period from February 1944 to October 1954. The total number of propeller shafts inspected was 331. Data regarding the inspection of stern tube and line shafts has been omitted.

	BB	CL	DD	Misc Ships	Totals
Shafts with no cracks..	14	45	23	118	200
Shafts rejected	7	1	4	1	13
Shafts repaired by welding	0	28	14	45	87
Shafts with minor cracks	7	8	12	4	31
Percentage of cracked shafts	50	45	56.6	29.7	

For all of the ships examined during the 1944-1954 period, 39 per cent contained corrosion fatigue cracks. Mr. Mills stated that in practically all of the cases in which cracking was found, the most critical area was immediately forward of the main strut bearing. The cracking was indentified as being of the corrosion-fatigue type which originated in areas of local stress concentration. Here the corrosion was aggravated by the fretting action between the shaft and the steel protector ring and the galvanic action in salt water between the shaft, the protector ring and the bronze bearing sleeve. Up to 1948, 56 per cent of all propeller shafts contained corrosion-fatigue cracks. This was reduced to 39 per cent for the 1944-1954 period, due to the much improved corrosion protection given the shafts after 1949. This will be covered later in the paper. Several shafts on active ships which have been in use for several years have been stripped of rubber at the Puget Sound Naval Shipyard and the shafts inspected by the magnetic particle method. None of these shafts have shown any indication of fatigue or corrosion-fatigue cracking.

FORCES TO BE CONSIDERED IN DESIGN

In designing propulsion shafting, due consideration must be given to not only the shaft, but also the masses connected to it. The assembly of shaft, propeller, engine and reduction gears is called the mass-elastic system. It is necessary to know the complete torque producing characteristics of the prime mover as well as the manner in which torque is absorbed by the propeller. The latter includes a knowledge of fluid flow into the propeller, as it is affected by hull form, strut arms, bearings and skegs, if any. Unusual operating conditions, such as an increase in torque and thrust while making turns at full power or contact with an object such as ice or a log must also be considered in designing the shafting. The effects of corrosion must also be evaluated. Finally, the amount of operation at full power and at cruising power is given consideration in a modern shaft design.

Mass-elastic systems of naval vessels may be classified as follows:

a. Geared turbine drive, with either one or more turbine casings. If the turbine has more than one casing it is called a branched system.

b. Geared diesel drive, either with or without intermediate gears.

c. Electric drives with or without gears.

d. Hydraulic coupling drives.

e. Direct reciprocating engine drive.

Each of these systems has different vibratory characteristics which affect the stresses in the shafting.

The overall stresses in a shaft have a steady and an alternating component. The steady component consists of nonvariant shearing and thrust stresses, resulting from the engine torque and the propeller thrust. Superimposed on these are the alternating components, consisting of bending stresses and vibratory stresses. The combination of these can cause fatigue failure at a point where the localized stress is high. The bending stresses at the propeller end of the shaft have a gravity component, and an off-center thrust component. The latter is due to the non-uniform flow conditions at the propeller and may be greatly increased if the propeller operates only partly submerged, as is the case in heavy weather or at light displacement.

DESIGN METHODS USED UP TO 1941

Previous to World War II, the Bureau of Ships of the Navy Department determined stresses in shafting by computation methods primarily developed for *statically* applied loads. Torque was computed by formula (1) for geared turbine, turbine-electric or diesel electric drives.

$$Q = 63024 \frac{SHP}{RPM} \quad \ldots\ldots (1)$$

where Q is torque in inch-pounds.

However, for either a reciprocating steam or diesel engine drive, formula (1) was modified by increasing this torque by an amount depending upon the number of engine cylinders, crank angle, and in the case of diesel engines, the type of cycle. The torque used for design purposes was thus an empirical determination. The thrust on the shaft was computed by the following relation:

$$T = \frac{326 \times SHP \times P.C.}{V} \text{ for geared turbine drive} \quad \ldots (2)$$

where T = thrust in pounds
P.C. = propulsive coefficient, as a fraction
V = speed in knots

For diesel and steam engine drives, formula (2) was modified by decreasing the thrust by an empirically determined percentage. The compressive stress due to thrust in the shaft ahead of the propeller strut bearing was computed by the Gordon-

Rankine column formula, assuming fixed ends and taking into account the deflection of the shaft, in accordance with formula (3).

$$S_t = \frac{T}{A}\left[1 + \frac{16L^2}{25000(D^2 + d^2)}\right] \quad \ldots\ldots (3)$$

where S_t = compressive stress due to thrust, pounds.
A = cross-sectional area of shaft, square inches.
L = center distance between bearings, inches.

The compressive stress in the tail shaft due to thrust, was computed from:

$$S = \frac{T}{A} \quad \ldots\ldots (4)$$

The shear stress, due to the torque, was computed by:

$$S_s = \frac{Qc}{J} = 5.1\,\frac{QD}{D^4 - d^4} \quad \ldots\ldots (5)$$

The bending moment, usually a maximum at the propeller end of the shaft, was taken to be:

$$M_b = 2\,WL \quad \ldots\ldots (6)$$

where W = weight of propeller assembly, pounds
L = distance from center of gravity of propeller assembly to after end of strut bearing, inches

The bending stress in the tail shaft is then:

$$S_b = \frac{Mc}{I} = \frac{10.2\,M_bD}{D^4 - d^4} \quad \ldots\ldots (7)$$

The state of stress at a critical point in the shaft was determined by the maximum tensile stress or Rankine theory of failure.

The maximum combined, or principal stress, on a tensile basis, was computed from:

$$S = \frac{S_b + S_t}{2} + \tfrac{1}{2}\sqrt{(S_b + S_t)^2 + (2S_s)^2} \quad \ldots\ldots (8)$$

The diameter of the shaft was chosen so that the stress computed by equation (8) should not exceed 9500 p.s.i. for An steel shafts used on surface fighting ships. On submarines, tenders, transports, tankers, tugs, supply and hospital ships, this stress did not exceed 8000 p.s.i. Properties of various shafting materials are given in Table I.

TABLE 1

Mechanical Properties of Shafting Materials

Material	Tensile modulus E, p.s.i.	Torsion modulus G, p.s.i.	Tensile strength p.s.i.	Yield strength (.01% offset) p.s.i.	Tensile F.L (in air) (complete reversals) p.s.i.
Steel					
Alloy #2	29.0×10^6	11.8×10^6	120,000	105,000	60,000
Alloy #4	29.0	11.8	120,000	100,000	60,000
Class An					
(Mo-Va)	29.0	12.0	80,000	45,000	40,000
An (2.75 Ni)	29.0	11.7	80,000	45,000	40,000
Class B	29.0	11.9	60,000	30,000	27,000
Class Bs					
(special)	29.0	11.9	75,000	40,000	34,000
Class Hg	29.0	11.6	95,000	65,000	47,500
Monel (Ni-Cu alloy)					
½" dia. to 3½" incl	26.0	9.5	87,000	60,000	37,500
over 3½" d. to 4" incl	26.0	9.5	84,000	55,000	36,000
K Monel	26.0	9.5	140,000	100,000	50,000
Aluminum bronze					
0.5" to 1.0" dia. incl.	16.0	7.2	105,000	55,000	35,000
Over 1"-2.0" incl.	16.0	7.2	105,000	50,000	35,000
Over 2"-3.0" incl.	16.0	7.2	95,000	45,000	30,000
Over 3" dia.	16.0	7.2	85,000	42,500	26,000
Naval brass (Comp. A)					
Up to 1" dia.	13.0	5.0	60,000	27,000	23,000
1"-2" dia.	13.0	5.0	57,000	26,000	22,000
Over 4" dia.	13.0	5.0	54,000	20,000	21,000

NEW ADDITIONS TO KNOWLEDGE

Reduction of propeller excited vibrations.

Since World War II considerable progress has been made in eliminating or reducing the causes of propeller excited vibrations on Navy ships. The following are contributory causes to such vibrations.

Skegs or bossings

These interfere with the smooth axial flow of water into the propeller and thus cause non-uniform torques and thrusts of propeller blade frequency. On ships such as LST's, where skegs are unavoidable, due to their importance during landing operations, streamlining of these has reduced vibratory excitations to one-third their value before streamlining.

Blade tip clearance

Small tip clearance excites vibrations in both hull and shafting by the interaction of the water thrown against the hull plates. The blade tip clearance is made at least one-fifth of the propeller diameter on all Navy ships, with preference given to one-fourth or more on larger ships.

Number of propeller blades

The greater the number of blades, the less violent is the excitation per blade. Three bladed propellers have practically disappeared from modern Navy ships and six bladed propellers are common. Care is taken, in choosing the number of blades, that the blade frequency within the operating range does not coincide with a natural torsional or longitudinal frequency of the mass-elastic system.

Off-center thrusts

These are due to a non-uniform flow of water into the propeller. While their existance has long been known, the severity of off-center thrusts was probably not suspected until the incidence of shaft failures on the Liberty ships. When a ship operates in a light condition or in rough water so as to ex-

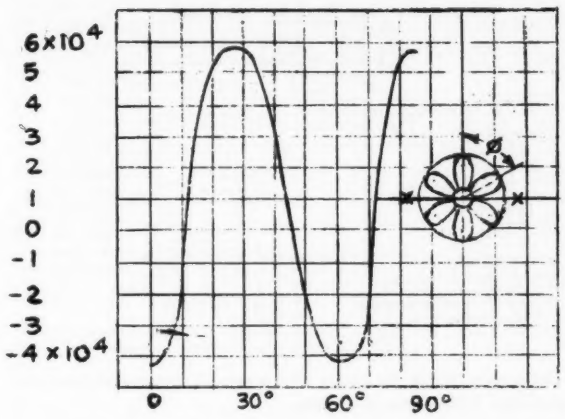


Figure 4. Blade Position from Vertical—moment due to off-center thrust destroyer type.

pose part of the propeller, off-center thrusts are more severe than when the propeller is completely submerged. Off-center thrusts are also increased during a high speed turn. The severity of off-center thrusts, which can be estimated from a wake survey, is shown in Figure 4. The moment acting on the shaft may add to or subtract from the gravity moment, although the former is more likely to occur than the latter. During rapid maneuvers from full power ahead to astern and vice versa, heavy transient thrusts and torques are developed by the propeller. The David Taylor Model Basin has conducted wake surveys of two and four shaft ships of different classes, but additional work needs to be done to arrive at firm average values.

Off-center thrusts tend to cause the propeller to wobble on the shaft. This condition is accentuated by a poor fit between hub bore and shaft and will often cause the propeller nut to loosen. Rubbing of the propeller against the shaft increases the tendency to cause frettage fatigue-failures of the shaft.

Magnitude of bending stresses

The Bureau of Ships has cooperated with the Society of Naval Architects and Marine Engineers in conducting full scale tests on single shaft merchant ships to determine bending stresses in the shaft just ahead of the propeller during operating conditions. Three such tests have been made and reported in reference 11. The Bureau has a program to conduct similar tests on two and four shaft ships. One such test has been partially completed on a destroyer but the data are not available at this writing.

Further full scale tests on transient torques and thrusts developed during full power backing conditions are being made under the sponsorship of the M-9 Panel of the Society of Naval Architects and Marine Engineers, with which the Bureau of Ships is cooperating. To date, tests have been made on a Navy destroyer. Results have not been published but unofficial analysis of data taken shows that thrusts and torques when going from full power astern to full power ahead may reach transient values of 175 per cent of those obtained during full power ahead operation.

Reduction of stress concentration

Since 1941 emphasis has been placed upon the elimination or reduction of stress raisers, particularly at the shaft keyways. Figure 5 shows the design of keyway with sled runner and spoon shaped form which is now standard practice on Navy ships. Figure 6 shows a typical propeller and tail shaft assembly. A detail of the method of sealing the forward end of the propeller hub to protect it from salt water corrosion is shown in Figure 7.

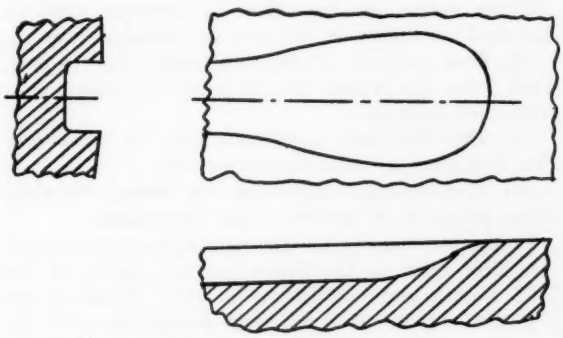


Figure 5. Keyway Detail.

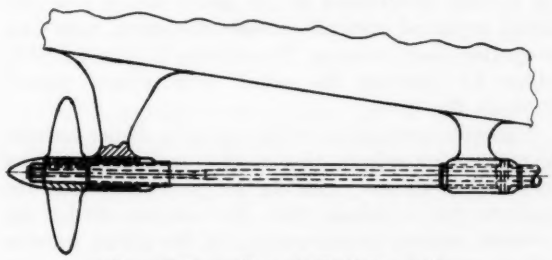


Figure 6. Propeller and Shaft Assembly.

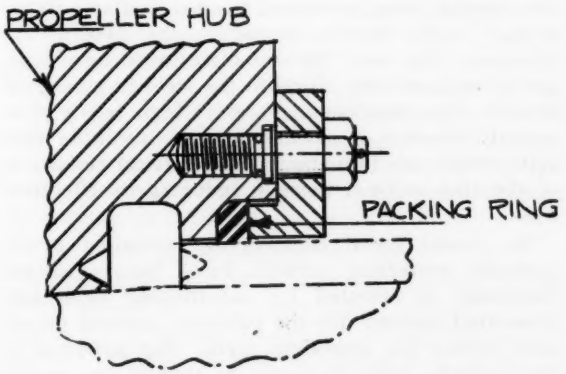


Figure 7.

Protection against corrosion

Corrosion of steel shafts and hull plates is severe at the stern of a ship due to bimetallic couple between the steel hull or shaft and the bronze propeller and because of the turbulent high velocity water which strips protective coatings. Steel is anodic to bronze and in the presence of salt water a galvanic battery is formed. As long as anodic and cathodic areas are equal, a uniform type of corrosion occurs. This is not the case at the shaft near the propeller or bronze sleeves, where localized pitting of a severe nature occurs if protective action is not taken. The corrosive reaction is electro-chemical because the solution of the iron which occurs at the anodic areas produces an electric current which flows to the cathodic areas which are at lower potential than the anodic areas.

Three steps can be taken to prevent electrochemical corrosion or the flow of galvanic current.

(1) One or both of the electrodes can be isolated from the water (electrolyte) by means of a protective coating.

(2) The electrode potentials can be equalized. This is known as cathodic protection.

(3) The metallic circuit can be broken by electrical isolation of the dissimilar electrodes.

Protective coating in the form of natural rubber was first used in the Navy on the shafts of the USS *Cassin* and USS *Shaw* in 1935. These coverings did not prove to be very permanent and frequent replacement was necessary. About 1942 the development of synthetic rubbers, particularly Buna N, had progressed to the point where this material replaced natural rubber for stern tube and propeller shaft coatings. The rubber is vulcanized in place by heating the shaft with steam passed through the bore.

Cathodic protection is the use of a direct current to prevent or reduce the rate of corrosion of a metal in an electrolyte by making the protected metal the cathode for a voltaic cell. The source of the impressed current is immaterial. In the oldest form in which cathodic protection has been used in the Navy, the impressed current is galvanic in origin, zinc anodes being connected to steel shafts or plates in salt water, thereby protecting the steel at the expense of the zinc. The zinc plates must be of high purity and perfectly fitted to the steel to give good results. Zinc protectors, if not of high purity, frequently develop a surface film of insoluble zinc salts which acts to increase the electrical resistance of the zinc surface, thereby reducing its effectiveness.

On recent naval construction, so-called active cathodic protection systems have been installed. Corrosion is arrested by substituting externally generated currents for the galvanic currents generated within the corroding metal. The potential of the cathodic areas is raised to that of the anodic areas until potential differences have been nullified and current ceases to flow. Figure 8 is a diagrammatic sketch of the cathodic protection system for a propeller and shaft. A copper slip ring with silver impregnated carbon brushes is installed on each shaft at a convenient location inside the hull. This provides a continuous ground to the hull for the propeller and shaft so that they will be protected from electrolytic corrosion. A silver chloride reference cell is placed at a convenient location along the hull and energizes a manual selector switch. If the hull potential is less than 0.85 volt, the reference cell energizes a manual selector switch which supplies power to the motor driving the variac and sends alternating current to the transformer. The rectifier sends the direct current to platinum covered anodes placed on the outside of the hull in strategic positions. No zinc protectors need be attached to hull or any of the appendages in this system. However, rubber covering of the shafts is still the practice, due to the possibility of current leaks through damaged parts of the rubber.

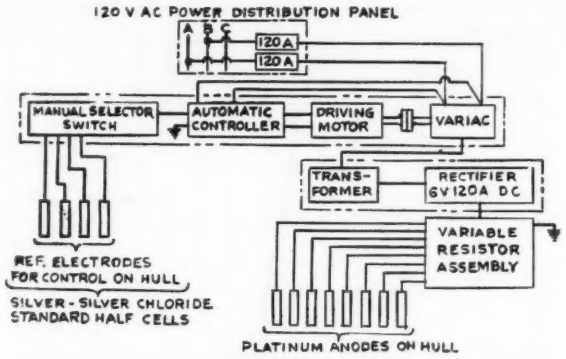


Figure 8. Block Diagram of Automatic Control System for Cathodic Protection of a Ship.

Over 400 Reserve Fleet ships have been placed under cathodic protection and plans are going forward to extend this to the entire Reserve Fleet. The problems of protecting Reserve Fleet ships at fresh water sites have not been entirely solved but sufficient success has been realized for the majority of ships involved so that directives have been issued to extend the docking interval of certain ships from 5 to 8 years.

In the active-ship field, many assorted types of experimental installations have been tried on various ships in service. Coupled with concurrent laboratory investigations, these installations have begun to pay dividends as adequate designs and installation techniques emerge. Efforts are now being made to standardize on service-proved installations. Systems using magnesium and zinc and externally energized systems using platinum-clad anodes are now being installed. Experiments with energized hull-anode systems using graphite are in progress. High silicone-iron and lead anodes for active ships are being investigated in Navy laboratories.

The subject of cathodic protection is covered in much greater detail than is possible in this paper by references 12 to 15, inclusive.

Cold-Rolling of Shafts

On recent construction, the Bureau of Ships has specified that the propeller shaft shall be cold-rolled, starting at the after end of the taper and extending forward to a point about one diameter ahead of the forward end of the after shaft sleeve. Rolling is accomplished with hardened steel rollers of 10 inch diameter and 1½ inch radius contour. Two such rollers spaced at 180 degrees in a suitable frame, form the rolling device. Roller loads are regulated to cold work the shaft to a depth of 0.50 inch. For a 15 inch diameter shaft made of steel having a yield strength of 50,000 p.s.i., the roller load will be 30,000 pounds. The same diameter shaft made of steel having a yield strength of 32,000 p.s.i., would be rolled with a roller load of 17,500 pounds. The roller load is gradually diminished at the forward end of the travel of the rolling device, so that the residual stress will be gradually reduced. Although it has been proven by laboratory and service tests on railway car axles that cold-rolling is beneficial in preventing fretting corrosion, the Navy is not at this time raising bending stresses in propeller shafts that are cold-rolled.

Stewart and Ellinghausen reported in reference 20 the results of flexural endurance limit tests made on rotating cantilever type specimens. Tests were made of both rolled and unrolled specimens. These were made of alloy No. 4 having the following properties.

	Alloy No. 4
Tensile strength, p.s.i.	141,000
Yield strength (0.1 per cent offset) p.s.i.	118,000
Elongation in 2 inch per cent	19.1
Reduction in area per cent	54.9
Brinell hardness	290

The unrolled alloy No. 4 material was found to have a flexural endurance limit in air of 71,000 p.s.i. When rolled, this material had an endurance limit of 83,000 p.s.i. in air. The fatigue strength of this material was decidedly lowered when the rotating beam tests were carried out in Severn River and natural sea water. The corrosion-fatigue strength of the steel in salt water was increased substantially by cold-rolling the test length of the specimens.

Reference 20 also reports the results of tests in rotating bending of a number of specimens with a tapered end mounted in a manganese bronze sleeve Figure 9. These tests were made to determine the effect of cold-rolling on fretting corrosion of a simulated propeller and shaft assembly. For specimens with ⅛ inch taper per foot, a pull of 3000 pounds was applied through a nut to draw and hold the tapered shank in the sleeve. It will be noted from Figure 10 that the fatigue limit of the alloy No. 4 rolled shaft assembled in the manganese bronze

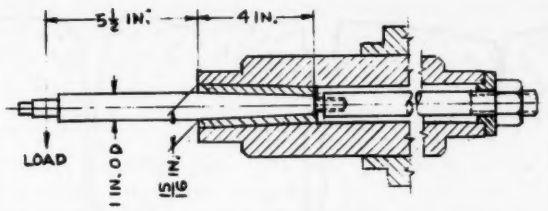


Figure 9. Rotating Cantilever Fatigue Test Specimen for Investigating effects of frettage. Normal Taper in. per foot—Pull up taper fit—3,000 pounds.

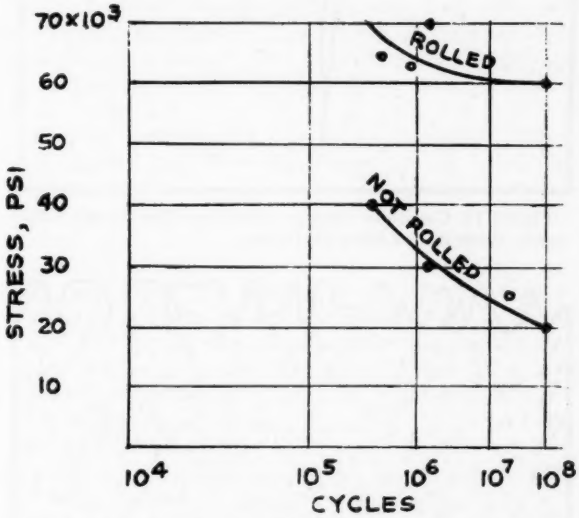


Figure 10. Alloy No. 4.
Fatigue Tests of Tapered Shafts Mounted in Manganese Bronze Sleeves.

sleeve is approximately 60,000 p.s.i. as compared to 21,000 p.s.i. for unrolled specimens. Fracture occurred in an area ⅛ to ¼ inch back from the face of the sleeve. This frettage band was characterized by dark discoloration and deposits with bronze streaks picked up from the sleeve.

Sections were taken from rotating cantilever fatigue specimens and prepared for microscopic examination to determine whether crack propagation in corrosive fatigue differed in rolled and non-rolled specimens. Figures 11 and 12 show non-rolled and rolled sections tested at 35,000 p.s.i. bending stress in braskish water. The rolled specimens withstood 24.6 million cycles and the non-rolled 1.035 million cycles before failure. Rolling the shaft surface blunts the crack and reduces stress concentration, thus delaying failure.

DESIGN METHOD, 1941-1956

In rebuilding the Navy between the two World Wars, emphasis was placed upon increasing cruising radius of warships, which required lighter machinery weights as well as increased economy of operation. As a result, the shafting design method was re-examined in 1941 in order to reduce weights

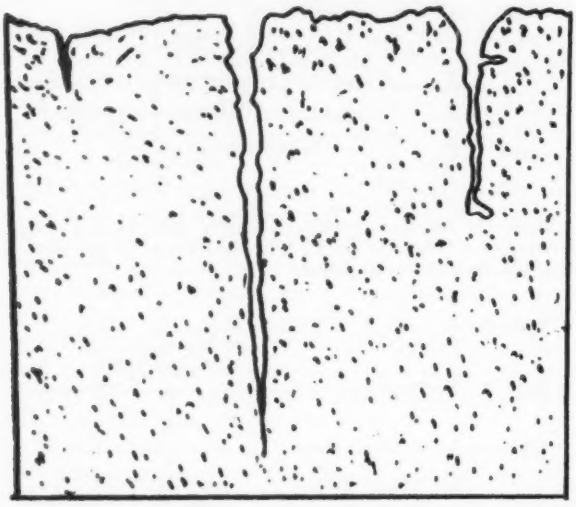


Figure 11. Corrosion, fatigue cracks in Alloy 4—not rolled stress, 35,000 PSI.; 1.035 x 10^6 Cycles.

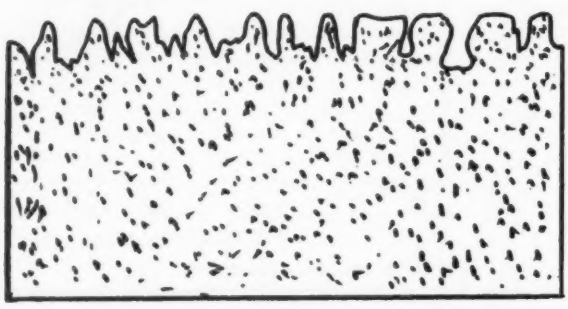


Figure 12. Corrosion Fatigue cracks in Alloy 4-rolled, Stress, 35,000 PSI.; 24.6x10^6 cycles.

without decreasing the reliability of the shafting. The general philosophy of design incorporated into the 1941 method was to combine the steady and alternating resultant stresses in accordance with the method of Soderberg, reference 9, to determine the factor of safety of the shafting, which was limited by the specifications. Advanced analytical methods of computing vibratory stresses were substituted for empirical methods used up to 1941 in order to reduce shaft weights. Stress concentrations at keyway corners and flange fillets were greatly reduced by the introduction or increase in size of fillet radii. An optional design of flange bolt with head was introduced, which could be used in lieu of the tapered, headless bolt that was universally used at the time.

The 1941 method of computation of shaft diameters took into account the effect of boundary layer on the propeller thrust by the introduction of a thrust deduction coefficient "t", in formula 9:

$$T = 326 \times \frac{E.H.P.}{V} \times \left(\frac{1}{1\text{-}t}\right) \quad \ldots\ldots\ldots\ldots (9)$$

The thrust deduction coefficient has values of 0.03 to 0.30 for different types of naval vessels.

Alternating stresses in propulsion shafting are classified as follows: (a) bending stresses due to gravity, usually a maximum at the propeller end; (b) torsional stresses due to excitation by either the propeller or the prime mover. Bending stresses due to a transverse natural frequency are rarely encountered in naval propulsion shafting, since every attempt is made to insure that this frequency is above the operating speed of the shaft. Alternating compressive stresses due to longitudinal vibration are low and are not included in design computations.

The maximum bending moment at the propeller, due to the weight of the propeller assembly, is assumed to occur at a point one shaft diameter ahead of the after end of the propeller strut bearing, an assumption probably very close to the truth for the rubber bearings used on naval vessels. The bending moment caused by the weight of the propeller assembly is usually the highest encountered, due to the closeness of bearings elsewhere along the shaft. Alternating shearing stresses, due to torsional vibration excited by either the propeller or the prime mover, constitute the remaining component of alternating stress, since alternating thrust stresses are considered to be so low that they are ignored. The propeller excited torsional vibratory stress is usually assumed to be 7.5 per cent of the steady shearing stress at full power or 500 p.s.i. whichever is larger, in cases where the ship does not have skegs or bossings, i.e., where the flow of water into the propeller is relatively undisturbed. When the ship is fitted with skegs or bossings, which is rarely, a wake survey is conducted by David Taylor Model Basin to determine the severity of the vibratory torque. In the case of USS *North Carolina*, fitted with skegs on the two inboard shafts, the torsional vibratory stresses were about 50 per cent of the full power shearing stresses (reference 4). Of the types of mass-elastic systems enumerated in the right hand column on page 155, only the diesel and the direct connected reciprocating steam engine drive have engine excited vibrations. Methods of computing the vibratory torques are covered in references 3, 5 and 6.

The steady stresses are combined by means of the following formula:

$$S_{s.r.} = \sqrt{S_c^2 + (2S_s)^2} \quad \ldots\ldots\ldots\ldots (10)$$

where $S_{s.r.}$ = steady resultant stress, p.s.i.

S_c = compressive stress due to thrust, p.s.i.

$= \frac{T}{A}$, where A = cross sectional area of shaft,

S_s = shear stress due to steady torque, p.s.i.

The alternating stresses are combined by a similar formula:

$$S_{a.r.} = \sqrt{(k_b S_b)^2 + (2k_t S_s)^2} \quad \ldots\ldots\ldots\ldots (11)$$

where $S_{a.r.}$ = alternating resultant stress, p.s.i.

S_b = bending stress, due to propeller overhang, p.s.i.
S_s = vibratory shear stress, p.s.i.
k_b = stress concentration factor at keyway end for bending
k_t = stress concentration factor at keyway for torsion.

The points of stress concentration at the forward end of the keyway do not lie in the plane where the maximum bending stresses are computed. However, inclusion of the stress concentration factors k_b and k_t is on the side of safety. Stress concentration factors were taken from reference 8.

Since the shaft is made of ductile material, the yield strength is taken as the criterion of failure for steady stresses and the endurance limit (complete reversals of stress) for alternating stresses. The highest bending stress, usually due to propeller overhang, is of shaft rotational frequency. Superimposed on this are smaller (usually) components of alternating stress of propeller blade frequency. In the case of reciprocating engine drives, additional components of a frequency depending upon the number of engine cylinders may also exist.

To determine the margin of safety, the method of Soderberg, reference 9, was used.

Referring to Figure 13, the combination of alternating and steady resultant stresses existing in the

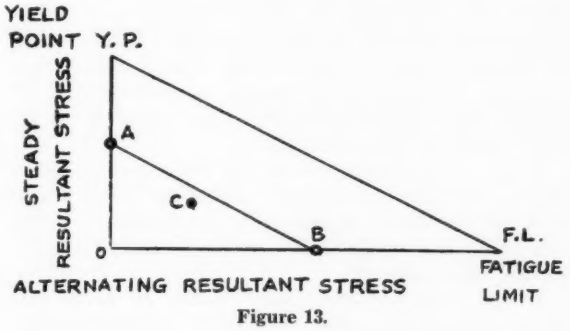


Figure 13.

shafting may be expressed by plotting these along coordinate axes. For each value of steady resultant stress, there is a certain value of alternating resultant stress that will cause failure. For example, if the steady resultant stress in a shaft is equal to the yield point, marked Y.P. on the vertical axis of Figure 13, failure is considered to have occurred even though no variable stresses have been applied. Since alternating stresses in the form of bending stresses always exist, the actual state of stress in the shaft is represented by a point such as C. Line AB is drawn so that the ratio of the distances AO and OB to the yield point and fatigue limit, respectively, represent the desired factor of safety. For propeller and stern tube shafting, both of which operate in water but are protected by synthetic rubber covering, this factor of safety was taken to be 2.25 in the 1941 design method, reference 1. For line shafting, where corrosion does not occur, the factor of safety was 2.0. The above relations are expressed mathematically by:

$$\frac{S_{s.r.}}{\text{Yield Strength}} + \frac{S_{ar}}{\text{Fatigue Limit}} = \frac{1}{\text{Factor of Safety}} \quad (12)$$

During the latter part of World War II it became the practice to base design on full power plus 20 per cent torque and factors of safety of 2.25 and 2.0 for propeller and line shafting, respectively. This was done because it was desired to include the additional torque developed during a high speed turn, at which time the propeller slows up although developing full power. The design method of 1944 differed from that of 1941 only in regard to details of design aimed at reducing stress concentrations and corrosion.

Shortly after World War II the Bureau of Ships investigated high strength steels in order to obtain lighter shafting than had been used during the war on surface combat ships. After considerable experimental work in forging, heat-treating and machining, it was decided to try alloy No. 4, a steel having 0.45 per cent C and 120,000 p.s.i. minimum tensile strength. Because of the higher properties of the alloy No. 4 steel, the stresses were allowed to become higher than they had been when using An steel. The failure of a destroyer tail shaft due to fretting corrosion, already discussed, led to the 1956 revision of the design criteria for shafting as follows. The total bending moment, M_b, at the propeller strut bearing is given by equations 13(a) to 13(d) for the different categories as indicated. This increase is due to the moment caused by the off-center thrust.

Surface Ships

$M_b = 2\,W(L + D)$ for multi-shaft ships .....13(a)
$M_b = 3\,W(L + D)$ for single-shaft ships. .....13(b)

Submarines

$M_b = W(L + D)$ for single-shaft submarine ...13(c)
$M_b = 2\,W(L + D)$ for two-shaft submarines ...13(d)

where M_b = total bending moment, inch-pounds
D = outside diameter of shaft, inches
L = distance from center of gravity of propeller assembly to aft end of bearing inches.

The bending stress due to M_b is not allowed to exceed 6000 p.s.i. Factors of safety for propeller and line shafting are based on the maximum shear theory of failure as before. For surface vessels other than ice breakers and for two-shaft submarines these are 2.00 and 1.75 for propeller and line shafting, respectively. For single-shaft submarines, the propeller and line shaft factors of safety are 2.25 and 2.00, respectively. For ice-breakers, these factors of safety are 3.5 and 2.25. The design torque is taken to be 120 per cent of the full power torque.

In the 1956 design method, reference (3), the maximum bending stress of 6000 p.s.i. was chosen after careful consideration of successful and unsuc-

cessful shafting designs. This represents the upper limit of bending stress, computed by the method described, as used on the propeller shafts of any of the major surface warships built since 1941 and which have given successful performance over a long period of time. The one failure attributable to high bending stress involved fretting corrosion of a high-strength shaft material (alloy No. 4) in contact with manganese bronze. In this case the computed bending stress was 8800 p.s.i. There is no real fretting corrosion limit of two materials in contact, since the S-N curve has no sharply defined break. However, Horger recommends (reference 18) 11,000 p.s.i. as the maximum allowable bending stress in steel car wheel axles with shrunk on wheels. It is emphasized that the actual bending stress in a shaft may reach peak values greatly in excess of the computed stress. This may explain why the above cited failure occurred at a computed bending stress of 8800 p.s.i.

The Navy specifications covering torsional vibration, reference 10, stipulate that the vibratory torque, excited by the prime mover, must not exceed 75 per cent of the steady driving torque at the same speed or 25 per cent of the full load torque, whichever is smaller. In the case of steam turbine drives, only 10 per cent of the full load torque is allowed instead of the aforementioned 25 per cent. The well known Holzer tabulation is used for computation of natural torsional frequencies and torques. References 3, 5, and 6 give details of the methods employed.

Calculations of longitudinal frequencies of the mass-elastic system are of particular importance when the excitation is high. This is the case when skegs or bossings are used or when propeller blade tip clearance is less than 20 per cent of the propeller diameter. It is specified in reference 10, that the first mode frequency of longitudinal vibration shall be either 15 per cent above the operating speed or shall occur at less than 50 per cent of full power speed.

SUMMARY

The method of designing propeller, stern tube and line shafting about 25 years ago was based on the principal stress theory of failure. No additional allowance for increase in torque during a high speed turn was made. Bending stress at the strut bearing of the propeller shaft was based on a liberal gravity moment of the propeller, thus unwittingly allowing for off-center thrust due either to operating with propeller partly submerged or poor fluid flow condition. Maximum principal stress was limited to 9500 p.s.i. for An steel shafts. Torsional vibratory stresses were not computed.

After 1941, the design of shafting was based on the maximum shear theory of failure. Greater efforts were made to reduce stress concentrations by the introduction of fillets. The recognition of one of the most frequent causes of earlier failure led to the use of stress concentration factors in design. Torsional stresses were computed and the occurrance of torsional and longitudinal frequencies limited either to low speeds or speeds above the operating range.

The introduction of higher strength materials brought with it the need for limiting the bending stresses, which cause fretting corrosion between bronze parts and the steel shaft. Also, the recognition of bending stress caused by off-center thrusts led to a re-evaluation of the method of computation of bending stresses at the propeller. The increase in torque which occurs during a high speed turn was also included in the design method of 1956, although this additional torque was included on designs made as early as 1950.

Due to the changes in design computation methods, a 23½-inch diameter propeller shaft for a modern battleship, designed by the method of 1941, would have been 25 inches in diameter if designed by the 1934 method.

Great progress has been made in protecting shafts against corrosion. Synthetic rubber coatings are now used on all shafts operating in water. In

TABLE II—*Summary of Design Methods*

Year of issue of design data sheets	1934	1941	1944	1956
Failure theory used	Maximum tensile stress	Maximum shear	Maximum shear	Maximum shear
Bending Moment, M_b	2WL* (L = distance from c.g. of propeller assembly to aft end of bearing)	W(L+D)	W(L+D)	2 W(L+D)** 3 W(L+D)†
Allowable stress	9500 psi total combined (An steel)	Not specified	Not specified	6000 psi max. bending stress at propeller
Design Torque	Full power	Full power	Full power	F.P. + 20%
Factor of Safety: Propeller shaft	Not specified	2.25	2.25	2.00
Line, stern tube shafts	Not specified	2.00	2.00	1.75

*(L = distance from c.g. of propeller assembly to aft end of bearing)
**(for multi-shaft surface ships other than ice breakers)
†(for single shaft surface ships)

addition, active cathodic protection systems have been installed on recently built ships and are successful.

Cold rolling of propeller shafts in way of propeller hub and strut bearing sleeves is now being done, although no credit for this is being given in the design of shafting.

Table II gives a summary of the principal design criteria used during the last 25 years.

CONCLUSION

Improvement in design methods has resulted in reduction of shaft size during the period covered by this paper, while reducing the number of failures due to alternating stresses and fatigue. Corrosion has been the principal reason for shaft renewal. Breakage of shafts at sea has been a rare occurrance in the U.S. Navy although the occurrance of corrosion fatigue cracks has been large. However, this has been decreased sharply since 1949, when steps were taken to remove steel waster rings and cover all the shafts operating in water with synthetic rubber. Improvements in cathodic protection will further reduce the incidence of corrosion of shafts. Due to improved welding techniques, it has been possible to repair a large percentage of cracked shafts. The recent introduction of cold rolling of the after end of propeller shafts is expected to eliminate fretting corrosion. This has been of rare occurrance, due to the low bending stress allowed in the past.

More attention is being given to the reduction of hydrodynamic exciting forces which have caused serious vibrations in the past.

Credit must be given to many classes of specialists who have contributed to the improvements in shafting during the past 25 years. The designer must take due cognizance of the test engineer, whose improved techniques have enabled better evaluation of forces and loads. The welding engineer, rubber technician, cathodic protection specialist and metallurgist have all made significant contributions that have and still are resulting in shafts that are more reliable yet of lighter weight than formerly. In particular, the writer gratefully acknowledges the assistance given by Mr. Roy Francis, of the Bureau of Ships, in supplying much of the data on cathodic protection.

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Experience with EBWR has been summarized by J. M. West and G. M. Ray in a report just published. Designed as a successor to the small BORAX I reactor, the purpose of EBWR was to provide experience and data from which extrapolations could be made to boiling water reactor plants of sizes of commercial interest. The designed goal of 20,000 KW heat output, or 5,000 KW electrical output, was considered the minimum satisfactory rating for this purpose. This large step increase in size, plus a shift to a more commercially feasible type of fuel element than that used in BORAX I, led to a highly conservative approach.

EBWR reached its rated output in late 1956, a little over two years after decision was made to proceed in its construction. It was operated at a 25% overload briefly after this, while safety features were being checked. After performing with excellent stability at full power and at the above overload, it was indicated that the possibility existed of a much greater overload. A testing technique was devised to estimate the maximum stable output. As a result, EBWR was operated to much higher than designed powers, reaching 61,700 KW in early 1958. At this power, the average power density in the coolant channels was about 75 KW per liter. Having a core uranium content of 6.1 tons, the resulting specific power is about 10,000 KW per ton of uranium.

The major conclusions from the experiment are briefly, (a) power density in this type reactor can be carried to considerably higher levels than originally anticipated; (b) future boiling water reactors should use uranium oxide instead of metal uranium in order to avoid uranium-water hazard. This will mean substantial increase in core size for the same output over EBWR.

—from NUCLEONICS
January, 1959

"THE MARINE ENGINEER AND NAVAL ARCHITECT"

GOTAVERKEN'S NUCLEAR TANKER PROJECT

This is a staff article which was published in the August 1958 issue of "The Marine Engineer and Naval Architect."

THE FIRST detailed study of a nuclear propulsion plant to be undertaken in Sweden has been completed by Lars Nordström and Jorgen Thunell of Gotaverken. The project is intended for a tanker of 65,000 tons d.w. with a machinery power of 30,000 s.h.p. The reactor is of the boiling water type in which the steam is formed in the core and fed directly to the turbines. The choice of this type of reactor was originally quite arbitrary but has since appeared to be favorable from many points of view.

The requirements of the reactor plant from an economical point of view are:—

(1) Low fuel cost.
(2) Low capital investment in machinery.
(3) Low weight.

To these must then be added the fulfillment of all safety demands. The proposed boiling water reactor, with slightly enriched uranium as fuel, ordinary water as moderator, and with turbines fed by reactor steam satisfies quite well the three economical demands. The safety demands may also be satisfied, if the reactor plant is located in an unmanned compartment amidships (a center tank) and is controlled from the engine room, right aft.

DIESEL-ELECTRIC FOR HARBOR PROPULSION AND PUMPING

Electrical power transmission from the turbines to the propellers has been adopted, and two independent 3,000-volt 50-cycle 11.7 MW turbo-alternators supply current to two 15,000 s.h.p. propeller motors. It has been anticipated that operation of the reactor may be forbidden in harbors and canals, and for propulsion in such circumstances two high-speed 2,000 KW diesel-alternators are provided, which would give the ship a speed of about 9 knots. These would also be used to supply power through transformers, for the cargo oil pumps.

Six 400 KW diesel alternators would supply all the auxiliary power needed for running the reactor pumps, and those associated with the turbo-alternators and the rest of the machinery on the ship. Two oil-fired header-type boilers, with a total steam capacity of 34 tons per hour at 170 p.s.i. would supply heating steam for the tank coils, Butterworthing, etc.

The machinery is arranged in two spaces, one amidships and one aft. In the amidship space is the reactor with its pumps and the main turbo-alternators with their condensers, pumps and auxiliaries. This space is normally unmanned. The water treatment plant for the primary loop system is located in a deck house above the midship engine room. In the after space are the propeller-motors, the auxiliary diesel engines, the harbor propulsion diesel engines, boilers and all other conventional equipment. The reactor control room is adjacent to the after engine room.

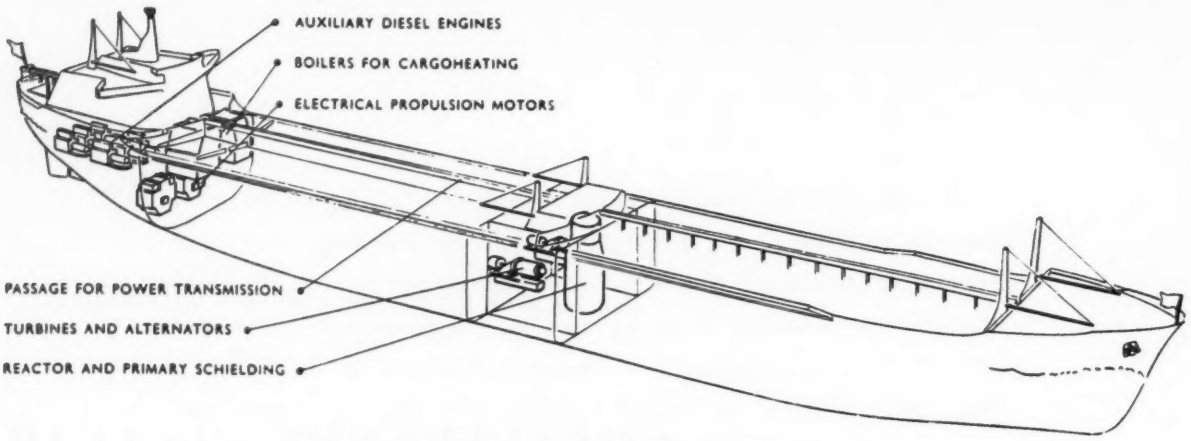


Figure 1. Sketch showing disposition of principal machinery items.

Several advantages are obtained with the arrangement described above. There is complete separation of those spaces which contain radio-active material or which might be filled with radio-active material in the event of a failure or an accident, and those spaces which people normally occupy, i.e. cabins, bridge and the remaining part of the machinery.

LARGE LOW-ENRICHMENT CORE

The reactor core is designed to contain quite a large amount (24 tons) of uranium, but with a very low grade of enrichment (1.0 per cent U-235) and a large cooling area of the fuel elements. The low enrichment results in a low fuel cost and the large amount gives a long irradiation time, 2½ years, before reloading is necessary. In a boiling water reactor, the large amount of uranium is no disadvantage in the construction of the pressure vessel, as the pressure is moderate (Tables III and IV).

The radiation shield, i.e. the biological shield of the reactor, has been studied very carefully. 100 mrem* per week has been stated as a general maximum permissible dose for the "reactor-personnel" and 10 mrem per week for the rest of the crew. As mentioned previously, no one is allowed to enter the midship space where the reactor is located while it is in operation. Hence the primary shield can be of relatively low weight, about 750 tons, instead of 1,000 tons. In spite of this, 20 minutes after shutdown the reactor space might be occupied for an unlimited time without risk of overexposure.

The operating costs are relatively favorable, thanks to the low degree of enrichment, even if the costs of the canning material, Zircaloy II, are considerable. The calculations show an annual cost exceeding that of a diesel ship but almost equal to the annual running cost of a turbine ship (Figure 4 and Table V).

* rem=röentgen equivalent man.

INSURANCE AN IMPORTANT FACTOR

A further important factor must not be overlooked. In order to operate a nuclear-powered ship, third party insurance will be necessary. The extent of this is unknown today, but it seems realistic to allow for an amount of £3½ m. as has been the case for several atomic power stations in the U.S.A. The premium might be 3 per cent or £100,000 per annum. This will raise the running costs of nuclear-powered ships considerably above that of conventional ships. Finally, the respective governments may possibly make certain charges for acting as guarantors for damages above the sum mentioned and this might perhaps also limit the ship's freedom of movement. The result will probably be a total operating cost that will be 20 per cent above that of an equivalent turbine ship and 60 per cent above that of a motor ship burning a boiler grade of fuel.

A close study of the safety requirements for a ma-

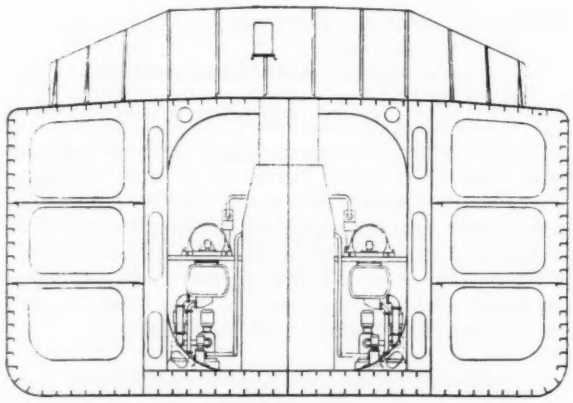


Figure 2. Section through the reactor space amidships. In this center tank, the reactor is flanked by the two 11.7 MW turbo-alternators.

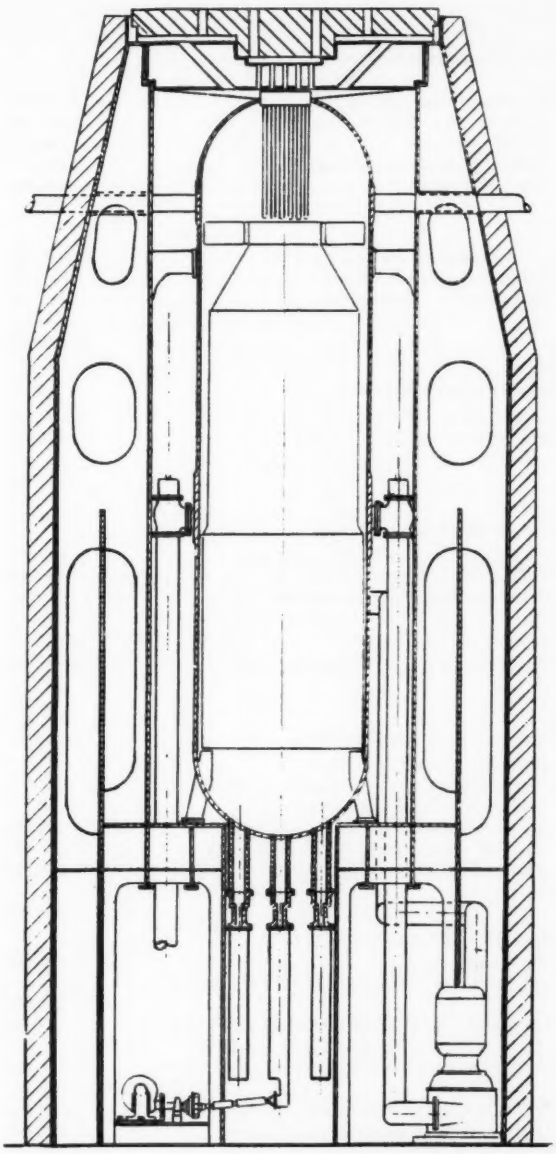


Figure 3. Reactor, container and circulating pumps with control gear and shielding.

rine reactor showed that it might be difficult to satisfy the demands for corrosion-resistance of the fuel elements in sea water, an objection which, it seems, applies to all other published designs. The Gotaverken engineers believe that this is the most severe problem concerning marine reactors. While the design of many details can be improved, these are deemed to be less important than the problem of the fuel elements.

A REALISTIC PROJECT

The project has been presented as realistically as possible and in many respects it tends to be favorable. In spite of this it is, from an economical point of view, not capable of competing with conventional ships. The fuel elements will probably not satisfy the safety regulations which are likely to be imposed, bearing ship casualties in mind. These two factors make for certain reservations with regard to the possibilities of building atomic ships not only according to this proposal but also in general. It is therefore necessary to continue the study of nuclear propulsion and we hope that this article will contribute somewhat to further work in this field.

The ship for which the propulsion system is planned would have the principal particulars shown in Table I.

TABLE I

Length overall	815 ft.
Length between perpendiculars	775 ft.
Beam	115 ft.
Mean draft, loaded	41 ft. 5 in.
Displacement, full load	84,000 tons
Deadweight	35,000 tons
Horsepower	30,000 s.h.p.
Speed on trial	18.25 knots
Speed in service	Abt. 17.75 knots
Number of propellers	Two
Propeller speed	98/101 r.p.m.

All accommodations are arranged aft, at a distance of over 300 ft. from the reactor. This distance is considered safe for small leakage of radio-active gases from the reactor compartment.

TABLE II

Thermodynamic data

Reactor power	100 MW heat
Steam pressure in reactor	600 p.s.i.
Heat content in steam from reactor	1,200 B.T.U. per lb.
Condenser pressure	0.85 p.s.i.
Adiabatic heat drop	400 B.T.U. per lb.
Adiabatic efficiency of turbine	68.5 per cent
Effective heat drop	275 B.T.U. per lb.
Alternator efficiency	97.8 per cent
Propeller motor efficiency	97.6 per cent
Transmission losses	1.5 per cent
Total steam flow	132 tons per hr.
Total heat consumption	330 m. B.T.U. per hr.
Margin for heat losses, etc.	3.5 per cent

Principal plant in forward machinery space

Reactor	One
Main loop circulating pumps (1,250 tons per hr.)	Four
Control rod mechanisms	Nine
Motorized valves for isolating reactor	Eleven
Turbo-alternator sets 11.7 MW, 3,000 volts, 3 phase	Two
Motor-driven lubricating oil pumps	Two
Condensers (18,300 sq. ft.)	Two
Alternator coolers	Two
Air ejectors and coolers	Two
Main condenser circulating pumps (4,000 tons per hr.)	Four
Extraction pumps (80 tons per hr.)	Four
Motorized valves for main steam/feed system	±30
Fans, bilge pumps, television cameras, etc.	—

The machinery in the reactor compartment will be remotely controlled from the after engine room. This will be made possible by introducing a very simple steam cycle, which while reducing the efficiency of the plant, will be counterbalanced by the use of a boiling water reactor in which the steam is produced in the reactor itself. No secondary loop is therefore necessary.

ENDURANCE OF 2½ YEARS

As light water will be present as a moderator, it will not be possible to use natural uranium in the reactor, but, by the introduction of a large core with 24 tons of uranium, a very low grade of enrichment will be sufficient. Thus a fuel with only 1 per cent U-235, or alternatively with some plutonium added to the natural uranium, will be sufficient. One charge for the core will give the ship an endurance of 2½ years.

TABLE III

Reactor core	
Shape	Cylindrical
Fuel	Uranium metal
Enrichment	1.0 per cent U-235
Canning (1 m.m. on elements, 2 m.m. on plates)	Zircaloy-II
Core diameter	5 ft. 9 in.
Core height	6 ft. 3 in.
Core weight	30.5 tons
Number of fuel elements (153 × 153 × 1,900 mm.)	100
Number of plates per element (10 × 144 × 1,900 mm.)	Six
Volume of cooling water in channels (2,300 liters)	2,300 liters
Total weight of water	2.6 tons
Pressure vessel details	
Total length	27 ft. 9 in.
Length of cylindrical part	21 ft. 0 in.
Diameter (internal)	6 ft. 5 in.
Cylinder thickness (40 m.m.)	1.58 in.
Thickness at strengthened part (65 m.m.)	2.56 in.
Material	2112 steel

TABLE IV

Reactor physical data	
Moderator/fuel ration (V_1/V_0)	2
Average thermal neutron flux (Φ)	7.9×10^{12}n/cm²
Number of neutrons per neutron absorbed (η)	1.48
Fast fission factor (E)	1.07
Resonance escape probability (p)	0.805
Thermal utilization (f)	0.885
Reflector savings (λ)	7 cm.
K.eff. with reflector	1.092
Reactivity losses due to:—	
Steam voids (15 per cent in cooling channels)	1.70 per cent
Temperature (20°C to 250°C)	1.65 per cent
Samarium	0.78 per cent
Equilibrium Zenon	1.70 per cent
Burn up (3,000 MW days per ton)	1.46 per cent
	7.29 per cent
K.eff. with regard to reactivity losses	1.012

TABLE V

Cost of fresh reactor core	
24 tons of uranium as UF_6	£657,000
Conversion of UF_6 to U-metal	111,000
Zircaloy-II	138,000
Fabrication of fuel elements	152,000
Control rods	14,000
Total cost of the reactor core	£1,072,000
Loan from "Atom Bank"	657,000
Shipowner's investment	£415,000
	£1,072,000
Value of spent reactor core	
Uranium as UF_6	£350,000
Plutonium in metallic form	239,000
	589,000
To be deducted:	
Reprocessing to UNH and PuNH	132,000
Converting UNH to UF_6	48,000
Converting PuNH to Pu-metal	34,000
Total value of spent reactor core	£375,000
Annual fuel operating costs	£ per year
Time in reactor—2.5 years	
Total leasing time (incl. cooling time, transport time, etc.)—3.5 years	
Cost of fissioned uranium (as UF_6)	123,000
Cost of reactor core (excl. UF_6 cost)	166,000
Processing costs (separation)	86,000
	375,000
Pu-credit	95,000
	280,000
Lease of U during operation time (4 per cent)	26,500
Lease of U during the rest of the time (4 per cent)	10,500
	317,000
Oil for diesel engines and boilers	30,000
Annual fuel operating costs	£347,000
Total annual operation costs	£ per year
Fuel as above	347,000
Interest and depreciation on £415,000 (12 per cent)	50,000
Insurance of uranium for 5 months (3 per cent)	3,500
Insurance of core for operation time (3 per cent)	20,000
Insurance of core for 7 months (3 per cent)	2,500
	423,000
Insurance for third party liability (£3,470,000 at 3 per cent)	104,000
Total annual operating cost	£527,000

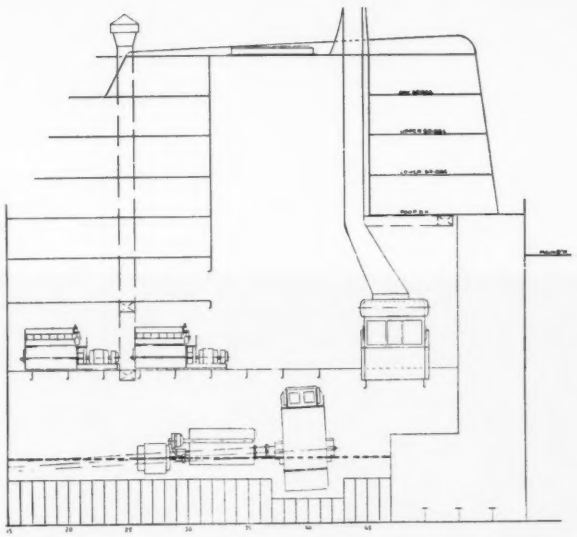


Figure 4. Elevation of after machinery space. The 400 kW auxiliary diesel alternators and boilers are seen on the flat. One of the 2,000 kW harbor propulsion and cargo pumping diesel alternators (apparently a Gotaverken T.O.P. opposed-piston engine) and a 15,000 s.h.p. propulsion motor are shown.

It is estimated that the cost of the ship, as delivered by the shipyard without fuel (i.e. with an empty reactor) will be 10 per cent higher than for a conventional ship, but there is still some uncertainty on this point. The increase in price, however, will be compensated by an increase in cargo-carrying capacity, especially if the ship operates via the Cape. In that case the nuclear ship will be able to carry 10 per cent more cargo than the conventional equivalent tanker.

However the shipowner's "fuel-bill" and his insurance costs will inevitably be much higher than for conventional ships.

CONCLUSION

The project has been made as realistic as possible and several studies with different detail design were made. The ship seems to have several good features but it will not be an economical proposition, and therefore it cannot be expected to compete with a conventional ship. It is also doubtful whether the fuel elements in the reactor will satisfy the requirements for safety which are likely to be enforced for marine reactors. Nevertheless, these remarks apply to all the projects so far published.

The energy released in the explosion of a 100 megaton nuclear bomb is approximately equal to the total amount of energy contained in the earth's magnetic field from the surface outward into space. Consequently, it has been postulated that bombs exploded high above the surface of the earth could possibly cause a distortion of the field. Since the energy in the earth's magnetic field within the surface of the earth is a very large fraction of its total energy, explosions at low altitudes would probably have little effect on the field.

—from SCIENCE NEWS LETTER
January 3, 1959

Official U. S. Navy Photograph

USS *Boston* (CAG-1) underway. The two missile launchers on the stern of this ship, contrasted with the two turrets in the bow, symbolize the revolution underway in naval armament.

JAMES N. KILPATRICK

THE CUSTOMER IS SELDOM RIGHT!

THE AUTHOR

born 1907 in Dundalk, Northern Ireland. Educated Philadelphia, Pa. public schools; attended Drexel Institute of Technology Evening College; formerly with Wm. Cramp Shipbuilding Co., Philadelphia, Pa.; currently civilian head of Norfolk Naval Supply Center's Technical Branch.

MANY large business enterprises actually owe their present prosperity to favorable economic and sociological conditions. However, they often prefer to credit their public relations policies with the major portion of their success. If any one feature of private business public relations policy were to be selected as exerting the most favorable influence, "The Customer is Always Right!" philosophy would undoubtedly win first place. Unfortunately, the converse is often the fact in actual practice. Customers are seldom right, and the Navy Supply System's "customers" are no exception.

Controversial though it may sound, this is a plain statement of fact. If the Navy Supply System's customers were always right, there would be no need for the current elaborate cross-reference media employed in cataloging Navy material. There would be no need for the mile upon mile of microfilm used in translating part numbers or descriptions into Standard Navy Stock Numbers. There would be small need for the impressive numbers of technicians presently engaged upon request document research in Army, Navy, and Air Force supply activities throughout the Department of Defense. There would even be no need for this paper!

If all the conferences held upon the subject of establishing and observing correct requisitioning procedures were to be conducted simultaneously, their combined uproar and multitudinous unrelated recommendations would rival that of a national political convention. It is extremely doubtful if much lasting good has come out of any of these discussions. The doctors mean well and are faithful in attendance upon the patient; but the doctors' combined services are expensive—and the patient doesn't seem much the better for all the perennial purging, dosage, and drastic surgery.

Witness the following random examples from requisitions received at the Naval Supply Center, Norfolk, Virginia. "Hand hole cover gasket." There are upwards of 300 hand hole covers on this lad's ship, most of them entirely different in size and in shape. "Nut, 1¾" wide by ¼" thick, painted gray." No mention of thread gauge or composition, although the end-user probably believed he had submitted an excellent description. He may even have considered a statement to the effect that the paint was chipped on the top of the nut.

While these are some of the more ludicrous examples of improper requisitioning, it is a sobering thought that the originals were submitted in good faith—and were approved by someone in authority.

Acknowledgement of the fact that their customers are prone to error in the preparation of request documents led to the current utilization of technical personnel in Naval supply field activities. Classified

as "Supply Item Identifiers" or "Equipment Specialists," depending upon the degree of technical proficiency and experience their duties demand, these commodity experts might well be called "Second Guessers to the Fleet." And that could include a few shore establishments!

A typical day's work on the part of an Equipment Specialist assigned to request document interpretation at NSC, Norfolk, would include such diversified actions as: interpreting non-standard descriptive data in terms of standard nomenclature and federal stock numbers; determining workable substitutes for emergency issue on material not in stock; recommending ship's force fabrication of non-stocked items; estimating reasonable prices on non-standard priced material; and interviewing a continual procession of visiting Fleet personnel who are in search of technical assistance on their requisitioning problems.

It must be clearly understood that *only technical material* is involved in this discussion. Beans and shoes and plum duff present little or no problem in requisitioning; but even so simple an electronic item as a resistor requires intelligent request processing. Data such as resistance value, tolerance, wattage dissipation, wire-wound or composition, ferrule, axial or radial wire leads and physical dimensions are all essential if the exact item desired is to be supplied. Even resistance to salt water and humidity factors must be considered. If such minutiae are all-important in requisitioning the amoebic resistor, what a wealth of detail must be involved in requisitioning an integrated Sonar installation! Such detail would approach the mass of detail found only in some misguided soul's Position Description.

Fortunately for all concerned, there is an easy way out of this supply morass. When the noun name, Federal stock number, quantity desired and unit of issue are all properly and legibly listed on the request document by the prospective end user, the recipient supply activity is in a position to take prompt action. Let us examine the case of this "perfect" requisition as it is processed through a typical Naval supply activity.

Immediately after scheduling by Requisition Control, clerical personnel in Stock Control are in a position to pull the applicable EAM (Electric Accounting Machine) card, verify the noun name and stock number against those appearing on the requisition and take action to supply or obligate the desired material. If substitution action appears in order, the matter is referred to a technician for his appraisal and counsel. It will be noted that in this instance the major expense has been for low priced clerical help rather than for relatively scarce and high priced technical talent.

At the other end of the spectrum, we find the requisition submitted *sans* name, *sans* number, *sans* everything. The only clue as to what this Fleet customer wants is, "Strainer—Basket, Allowance List Group S48-1, page 41, line 29." Since interpretation of allowance list data is best handled by technical personnel, this particular item was referred to an Equipment Specialist for research in an attempt to supply the item.

The search was ended as soon as begun. Line 45 of the same Allowance List reference page states: "Fabricate by ships force or repair facility per NAVSHIPS 4060 Part II." Clearly the item is *not* supplied or even stocked, and should not have been requisitioned in the first place. In the second place, even casual checking of the requisition aboard ship would have exposed the obvious error and prompt cancellation could have been effected. As it was, considerable delay and expense were incurred before corrective action could be taken *in this instance.*

The words "in this instance" are used intentionally. Scarcely a day goes by but what some other individual blithely types "Strainer—Basket" on his requisition and still another individual signs his approval in the satisfaction of a job well-done.

In the shadowy realms of humor, we find another extreme but actual case. A certain "high-powered" vessel submitting an extremely sketchy description of an item was contacted by phone in an effort to ascertain the item's equipment application. The shipboard storekeeper promised to do his best and would call back within the hour. Evidently a man of his word, he called back within the hour, regretting that he was unable to find the equipment application. All he had was a standard Navy stock number for the item—and could we do anything with *that!*

Midway in this requisitioning spectrum are the average ship's force. Conscientious, but obviously not completely informed, they list the descriptive data which *they* consider adequate—but which "ain't necessarily so!"

What, then, is the answer to the vexacious requisitioning problem? Does the solution lie in pictorial allowance lists, pictorial EAM requisitions, detachable samples to be forwarded with typewritten and thrice-verified request documents? Or is intensified on-the-job training of Fleet and shore establishment supply personnel the answer? Perhaps a combination of the lot—?

The writer has indoctrinated many officer, enlisted, and civilian personnel in the mysteries of technical interpretation of request and receipt documents. In all of these indoctrinations, three major points were emphasized: list the official noun name of the desired article; list the current Federal stock number, where known; *and* list the applicable manufacturer's name, part, drawing, and piece number as *corollary* information.

Those who follow these recommendations are among our best and most valued customers.

CONTROLLED-ATMOSPHERE ARC WELDING

ACKNOWLEDGEMENT

This is a slightly abridged version of an article appearing in the December 1958 issue of "The Welding Journal." The authors are N. E. Weare and R. E. Monroe, of Battelle Memorial Institute, Columbus, Ohio.

INTRODUCTION

ARC WELDING is always conducted in some type of gaseous atmosphere. This atmosphere may be generated from fluxes, supplied from a cylinder, or may simply be air. As arc welding developed from bare wire and covered electrodes for welding steels to inert-gas-shielded processes for welding metals such as aluminum, zirconium and titanium, greater control and efficiency of gas shielding has become important. Controlled-atmosphere arc welding, as discussed in this paper, will be limited to welding operations in essentially inert atmospheres. This paper presents a summary of recent developments in this area, with emphasis on techniques involving shielding in addition to that obtained with simple shielding cups. Weld shielding with carbon dioxide and other gases which may show inert behavior under special conditions* is not included in this paper. However, the term "controlled-atmosphere welding" also applies to the use of these gases.

Widespread use of shielding of the molten weld pool with inert gas is a relatively recent development in the welding industry. The first welding process to utilize commercially an inert-gas shield to protect the weld pool was the tungsten-arc process introduced in the aircraft industry in the early 1940's. At that time, it was considered only a manual process which had solved some of the problems involved in welding magnesium alloys. A few years after the appearance of the tungsten-arc process, the inert-gas-shielded consumable-electrode process was developed. Research in arc theory and improvements in shielding-gas purity and shielding methods have prompted many developments, so that today the inert-gas-shielded welding processes are applied to the welding of more metals than any other arc-welding process. In these processes, the electrode, arc column, molten weld pool, and, in the case of a consumable electrode, the metal being transferred through the arc, are shielded by flowing inert gas. Argon and helium are the only truly inert gases commercially used for welding, but mixtures of these with oxygen or hydrogen are used for special applications.

In recent years, many new materials have come into widespread use, because they possess properties which make them desirable for use in atomic energy, missile and jet-aircraft applications. Properties such as ductility or corrosion resistance of zirconium, titanium, molybdenum, niobium, tantalum and similar reactive metals are lowered when the metals are contaminated with small amounts of gaseous impurities. These impurities, primarily oxygen, nitrogen and hydrogen, which are picked up from air, contaminate welds in these metals that are not shielded from air.[1, 2] The degree of shielding required in welding reactive metals depends to some extent on the specific application. Generally,

* Nitrogen is an inert atmosphere for welding copper.

better shielding is required for reactive metals than for materials such as aluminum or steel. Initial improvement in weld shielding of reactive materials was made by adding trailing shields to the standard shielding cups. These provided gas coverage of weld metal which was still hot enough to be contaminated when exposed to air. Flowing inert-gas shields were further improved by the development of: (1) gas backups to protect the root side of the weld; (2) leading shields, generally used in conjunction with trailing shields, to prevent oxide formation in the joint ahead of the molten weld pool; (3) dragging shields which move in contact with the material being welded and act as small welding chambers; and (4) improved jigging to chill the weldment rapidly after welding to a temperature at which contamination will not occur.

Some materials and components require exceptionally good shielding during welding. In these cases, welding is done in a closed system which is sealed off from the atmosphere. Early systems were generally flow purged of their original atmosphere. However, with the growing need for even better shielding, vacuum-purged systems have come into widespread use.

This paper discusses some of the general considerations of controlled-atmosphere arc welding, shielding systems open to the atmosphere, and systems closed to the atmosphere.

GENERAL CONSIDERATIONS

Two problems are common to all controlled-atmosphere arc-welding techniques. These are tests to measure shielding-atmosphere purity and the selection and handling of shielding gases.

The purity of the shielding gas cannot be measured easily at the arc where it is really significant. This fact has forced the use of various indirect measurements which may not appear to be true measures of gas purity. However, if such indirect measurements are properly correlated with the conditions that exist during welding and with final joint properties, they are usually the quickest and cheapest methods of controlling gas purity. In closed systems, the gas can be analyzed, but this is slow and costly. It is also difficult to obtain a sample of gas which is representative of the gas near the arc. Once an arc is started, absorbed and adsorbed gases are released from the materials which become heated. These gases are then free to contaminate the metal being welded. In systems open to the atmosphere, it is nearly impossible to measure shielding-gas purity during the welding operation. Some investigators have used the Schlieren method of determining the area protected by a flowing-gas shield; [3] others have used the aluminum and titanium spot method.[4] In the welding of some materials, the degree of protection provided by the inert-gas shield is indicated by the degree of discoloration of the weldment. With materials such as titanium, zirconium, tantalum, niobium and molybdenum, the tolerance for impurities is so small that the absence of discoloration is not an indication of adequate shielding. For all shielding methods, the best way to determine whether the shielding is adequate is to make and test sample joints. This will indicate whether the degree of contamination is sufficient to affect adversely the desired properties of the joint. Atmosphere purity is expressed in numerous ways with some resulting confusion. Figure 1 shows the relationship between several common terms used to describe gas purity.

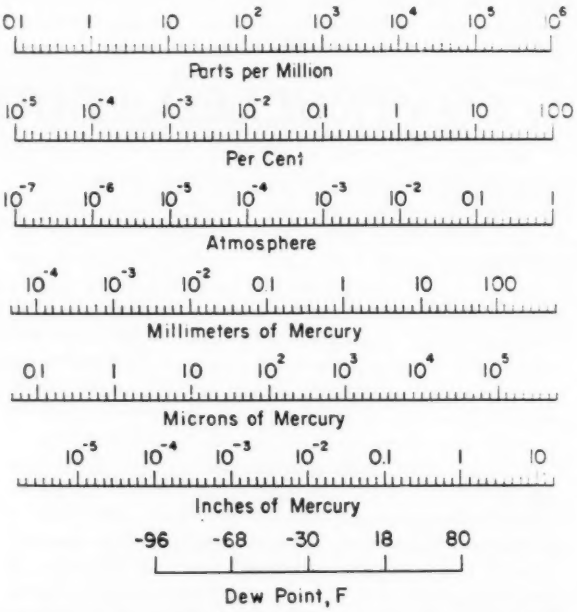
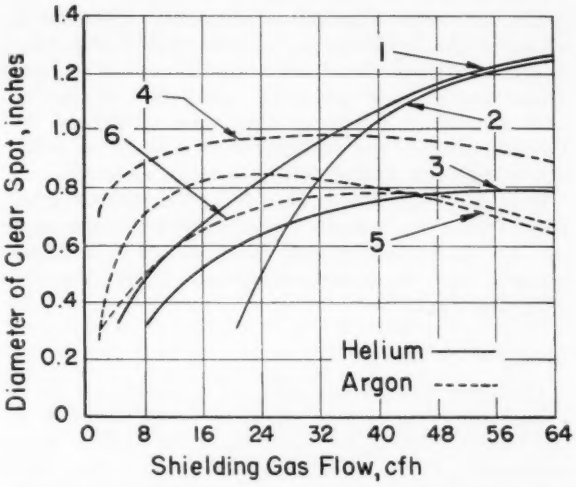


Figure 1. Comparison of units used to express residual impurities in an atmosphere. (Note that all scales are logarithmic)

Many places exist where the high-purity gas obtained from a gas plant can become contaminated before its use in shielding a weld. Most inert gas used for welding is not sold to a guaranteed purity although one manufacturer recently started such a policy. Slight differences in gas purity usually exist between cylinders of a given gas and, in some cases, suitable cylinders for very high-quality shielding must be selected. Any condensable vapor, such as water, will cause more contamination of shielding gases as the cylinder pressure is lowered. Gas contamination can occur from any vapor that condenses in the gas lines of equipment. In closed systems, condensed vapors are probably the major source of contamination. Contamination from condensed vapors can be minimized by leaving inert gas in the shielding-gas lines. Condensed vapors can be removed from a shielding system by heating during the purging cycle.



Curve Nos.	Nozzle Diam., in.	Nozzle-Work Distance, in.
1 and 4	$\frac{5}{8}$	$\frac{3}{16}$
2 and 5	$\frac{5}{8}$	$\frac{3}{8}$
3 and 6	$\frac{3}{8}$	$\frac{3}{8}$

Figure 2. Relationship between shielding-gas flow and gas coverage for helium and argon with varying nozzle sizes and nozzle-work distances.

Effective shielding of welds made in air can be obtained with either argon or helium. Generally, the flow rate required for helium is 1.5 to 2.5 times the flow rate required using argon under similar conditions. With both gases, the shielding device should be brought as close to the weld as possible to insure adequate exclusion of atmosphere contaminators. Figure 2, drawn from data presented by Gibson,[4] illustrates the effect of gas flow on the weld area shielded from the atmosphere for argon and helium, with different nozzle-to-work distances and shielding-cup sizes.

The area shielded with a given nozzle diameter and nozzle-to-work distance increases to a maximum and then decreases when the gas-flow rate is increased. Below this maximum, not enough gas is available to cover the entire area under the nozzle; above the optimum rate (at the maximum area) the flow becomes turbulent and air becomes entrapped in the shield. At a certain distance from the shielding nozzle, the gas flow will change from laminar to turbulent flow which entraps air in the shield. It is for this reason that the nozzle-to-work distance should be held to a minimum. If the nozzle-to-work distance must be increased, the gas flow must also be increased. Since there is an optimum gas-flow rate, it is apparent that there is also a nozzle-to-work distance beyond which adequate shielding cannot be obtained. As the nozzle size is increased, gas flows must be increased proportionately to provide adequate shielding. When proper gas flows are used for the various diameter nozzles in normal use, larger areas can be shielded when larger diameter nozzles are employed. Excessively large-diameter nozzles will not provide a proportional amount of increased shielding and may provide less shielding than a smaller diameter nozzle due to uneven gas flow. When large areas require shielding, leading trailing or dragging shields should be used in conjunction with the shielding cup.

EQUIPMENT AND TECHNIQUES

There are several methods by which normal shielding methods may be improved for the welding of materials easily contaminated by air. Normally, only a shielding cup is used to protect the molten weld metal. Better shielding can be obtained with the equipment and techniques described in the following sections.

OPEN SHIELDS

Shielding equipment which is used outside of complete enclosures includes shielding cups, trailing shields, dragging shields, gas backups, and special jigs and fixtures. These are discussed more fully below.

Shielding Cups

Shielding cups are standard equipment with all inert-gas-shielded welding torches. These cups are

SHIELDING DEVICES

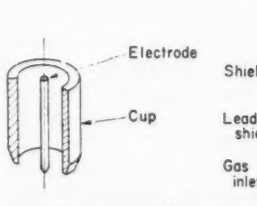


Figure 3a. Shielding cup.

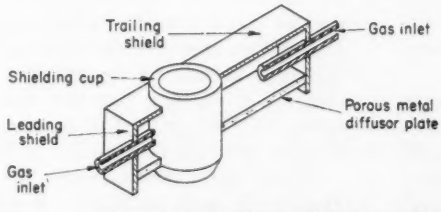


Figure 3b. Trailing and leading shields.

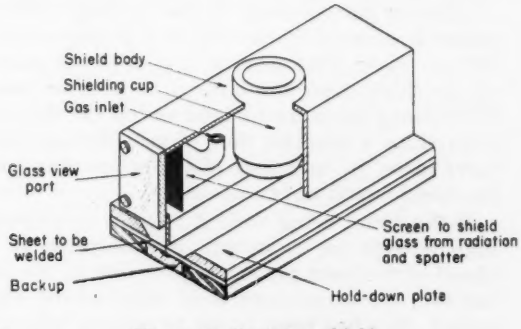


Figure 3c. Dragging shield.

either conical or cylindrical in shape and fit on the welding-torch body concentric with the electrode. This is illustrated in Figure 3a. Cups are generally made of pyrex or a ceramic for low- and medium-current tungsten-arc welding and copper with water cooling for high-current tungsten-arc welding and consumable-electrode welding.

The shielding cup provides excellent protection for the electrode, arc, material being transferred through the arc, and the molten pool. Adequate shielding can be provided by a shielding cup when the weld is small so that all the material not protected by shielding gas is below a temperature at which oxidation or contamination can occur. For most welding applications involving the reactive metals, oxidation or contamination of the metal outside of the shield area will occur. To provide maximum shielding with a shielding cup, use the largest available cup with the recommended gas flow and hold the nozzle-to-work distance to a minimum. The data published by manufacturers have been computed for conventional metals and may require changes when welding reactive metals. As an example, ductile tungsten-arc welds were made in 1/16-in. thick molybdenum sheet using a standard 5/8-in. diam. gas nozzle.[5] This nozzle diameter is much larger than needed for similar welds on conventional materials such as aluminum or stainless steel.

Shielding cups are used in conjunction with all other shields which are open to the atmosphere since they provide the best shielding for the molten weld pool. Cups are also used in many of the flow-purged closed systems in which gas flow is maintained while welding.

Trailing Shields and Leading Shields

Many of the materials mentioned in this paper can be contaminated just by heating in air. With these materials, shielding must be provided for the weld metal and heat-affected zone just behind the molten pool. This can be accomplished through the use of a trailing shield. One type of trailing shield is shown in Figure 3b. Shields of this type have been used with success on metals such as titanium and zirconium.[6]

Uniform gas coverage by the trailing shield illustrated is assured by the use of a porous-metal gas-diffuser plate. This plate is brazed to the underside of the shield near the bottom. A positive pressure of shielding gas is maintained within the shield body to produce a constant flow of gas. Without the diffuser plate, gas coverage of the entire area covered by shield would not be assured.

If the metal being welded reaches a temperature high enough for oxidation or absorption of gases ahead of the inert-gas shield provided by the shielding cup, the subsequent weld may become contaminated. This has been found to happen when welding molybdenum which possesses a high melting point and high thermal conductivity. The metal ahead of the shielding cup can be protected by the addition of a leading shield to the shielding cup. These shields are generally used in conjunction with a trailing shield as illustrated in Figure 3b. Leading shields are constructed the same as trailing shields but do not shield as large an area.

For best results, the leading and trailing shields should have gas supplied separately from the supply for the shielding cup. Because of their larger orifices they require greater gas flows than do shielding cups.

Dragging Shields

Dragging shields are used as a substitute for a closed shielding system when it is not practical to use closed systems; for instance, when welding large structures. These shields consist of small chambers mounted in conjunction with a shielding cup as illustrated in Figure 3c. The bottom of the shield is open, and the shield is constructed so that it conforms to the shape of the joint surfaces to provide adequate shielding. Small openings may be provided at the base of the unit to allow the shielding gas to flow from the shielded area. High gas flows are required to prevent back diffusion of air into the shielded area. Diffuser plates, similar to those used in leading and trailing shields, may be used to provide uniform gas flow over the area to be shielded. A shielding cup must be used to insure protection of the molten weld pool. Shields of this type have been successfully used for the welding of reactor components of Zircaloy-2.[6]

Backups

Backups have three important functions: (1) to support the molten weld metal and govern the contour of the root of the weld, (2) to protect the root of the weld from the atmosphere, and (3) to aid in chilling the weldment to the desired degree. Gas backups are generally required for welding materials which are easily contaminated by air. The types of backups to be considered in this paper are: solid metal, directed gas flow, simple gas flow, diffused gas flow, and pressurized gas backups.

The thickness of the material to be welded governs the type of backup to be used. Thin material require a metallic backing to support the molten metal and to chill the weld to prevent excessive melting and burn-through. Copper is generally used as the backup material. Heavier gages of material can be welded using backups which do not support the molten metal or chill the weld to a great degree. Backups should be designed to provide the desired degree of chilling for the thickness and material being welded, as well as to provide adequate shielding for the root side of the weld.

When using gas backups, the gas flow should be regulated and generally kept at relatively low levels to prevent interference between the backup

gas and the shielding gas protecting the top of the weld. Gas flowing through the unwelded joint can interfere with the upper-inert-gas shield and cause turbulence allowing entrainment of air in the shielding gas.

The simplest type of backup consists of a copper bar. This type of backup usually has a small groove located under the weld joint to allow complete weld penetration without pickup of backup material by the molten weld metal. The part being welded is clamped tightly against this backup so that little air remains at the root side of the joint. Contamination from the small amount of air in the groove beneath the joint is held to a minimum by rapid cooling of the weld to a temperature at which contamination cannot occur. Excessive heating by the arc might allow contamination of the weld by backup material; however, proper adjustment of current, arc voltage, and weld speed, and water cooling of the backup will lessen the chance of contamination from this source. Inert gas may be allowed to flow along the groove to offer some improvement in shielding at the root side of the weld.

The simplest gas backup consists of a tube or nozzle directing a stream of inert gas at the root of the molten weld pool. This type of shield sometimes contains a trailing and/or leading portion. The directed-flow type of gas backup is used for welding thick sections which do not require chilling. Directed-flow gas backups do not provide the degree of shielding provided by the other types of gas backups discussed in this section. This type of backup has been used for welding reactor components of Zircaloy-2.[7]

The gas backup shown in Figure 4a is very similar to the solid-metal backups. The groove is generally slightly deeper and gas outlet holes are closely spaced along this groove. These holes are connected to a gas-supply manifold drilled through the length of the backup. A major drawback to this type of backup is the difference in gas flow at various points along the backup. Gas flow is higher near the supply end of the backup and gradually becomes lower further away from the supply end. Some backing plugs for welding thin-walled tubing are of this type. In this instance the groove is machined around the circumference of the copper plug and the gas orifices are drilled radially to join the gas-supply tube. Gas backing plugs have been used for butt welding Zircaloy-2 tubing.[8] The backup shown in Figure 4b produces a more-even gas flow by maintaining a slight positive pressure below the porous-metal diffuser plate. These two types can be used with thin sheet since they also will produce a chilling effect on the weld.

The pressurized gas backup, Figure 4c, is used when rapid heat transfer is not desired, but support for the molten metal is required.[9] The sheet being welded is clamped against the gasket and a slight pressure is maintained in the backup to support the molten weld metal. Good joint fitup is required to prevent excessive escape of gas through the unwelded joint. Leakage is sometimes prevented by placing tape over the joint and removing it just ahead of the progressing weld. As the weld progresses, less gas flow is required to maintain the desired pressure. If the gas flow is not decreased as the weld progresses, the flow of gas through the unwelded section of the joint will become excessive and turbulence will be introduced into the upper inert-gas shield.

Once the first pass of a multipass weld has been completed, a gas backup may not be required unless the heat from subsequent passes raises the temperature of the root pass to a temperature at which contaminators can be absorbed from the atmosphere.

Jigs and Fixtures

The welding jigs and fixtures used in inert-gas-shielded arc welding play an important role in suppressing the contamination of weldments by gaseous impurities. By providing adequate chilling of the weld metal and heat-affected zone, the weldment can be rapidly cooled below the temperature at which contamination will occur. Chilling also reduces the size of the area which will require shielding by an inert gas. However, chilling cannot be used with all materials since some materials will crack and others will have their metallurgical properties adversely affected if the chilling is too rapid.

CLOSED CHAMBERS

Better protection than that afforded by the various "open" shielding devices can be obtained using

GAS BACKUPS

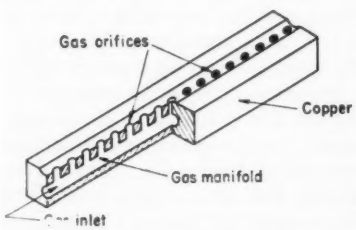


Figure 4a. Simple gas flow.

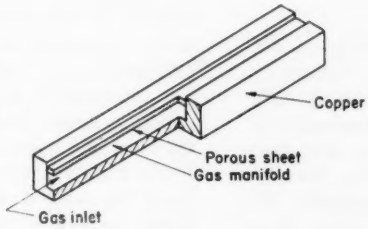


Figure 4b. Diffused gas flow.

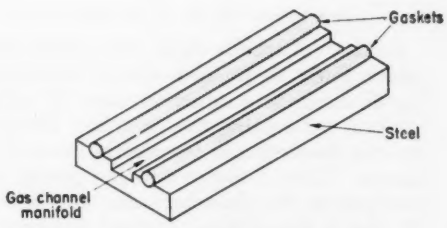


Figure 4c. Pressurized gas backup.

closed chambers to surround the area to be welded. In closed chambers, either a static or continuous flow of shielding gas can be employed during welding. If the gas flow is maintained, it should be vented through a mercury or low-vapor-pressure oil trap to prevent back diffusion of air into the working chamber. The use of a static atmosphere may create very uncomfortable working conditions for manual welding. Heat will build up during any long welding job and the resulting rise in both temperature and pressure will force the operator to interrupt his work. Use of cooling jackets on the chamber can minimize this problem.

The purity of the atmosphere in a static system can be improved by the use of a gettering operation. The simplest gettering method is to melt titanium or zirconium with the welding torch before starting an important welding run. Either of these metals will absorb large quantities of oxygen and nitrogen. Gettering of a static atmosphere is probably a more reliable method of maintaining gas purity than methods involving the use of gas purification trains for the incoming gas.

Many designs of closed chambers have been used, but these can be classified into two basic types: flow purged and vacuum purged. Flow-purged chambers depend on a gas flow to remove the air contained in the chamber, while vacuum-purged chambers exhaust the air before replacing it with gas. The removal of residual impurity gases and vapor by flow purging is not so effective as a vacuum purging.

Flow-Purged Chambers

Flow-purged chambers are generally useful in welding parts which require additional shielding for protection of the heat-affected zone as well as the molten weld pool. These chambers can be further divided into types depending on a fixed or collapsible construction.

TABLE I—*Theoretical Gas Composition After Purging Collapsible Chamber*

Purging cycles	Ratio*	Initial gas remaining, ppm — 20	10	4
1		50,000	100,000	250,000
2		2,500	10,000	62,500
3		63	100	3,900
4		0.004	0.01	16

* Expanded volume divided by collapsed volume.

In the collapsible type, the initial volume of air which must be purged is kept small by collapsing the chamber to a minimum size. By alternately filling and exhausting the chamber, the percentage of air can theoretically be readily lowered to very low figures. Table I shows the gas purity after successive purges for chambers that can be expanded 20, 10 and 4 times their original volumes. After four purges of a chamber that can be expanded 20 times, the purity of the gas is extremely high, assuming perfect mixing and no contamination from the incoming gas or other source. At smaller ratios, more purges are required to obtain equivalent gas purity. In practice, however, such purity is seldom attained with this type of chamber since contamination from other sources increases the air retained. Either rubber or plastic must be used in collapsible chambers. Leak-tight joints in these materials are hard to obtain and some air will actually leak through them. Collapsible chambers are usually used for manual welding.

A fixed, flow-purged chamber depends entirely on the displacement of impurity gases by incoming shielding gas. Chambers of this type are satisfactory if the dimensions are small and they are constructed so that a steady gas stream is present to remove the impurity gas. Large chambers of this type are effective only if long purging cycles are used or if the chambers are kept full of inert gas once they are purged. In the latter case, separate access chambers are provided for moving parts in and out of the welding chamber.

Vacuum-Purged Chambers

Chambers that are evacuated before refilling with shielding gas are used to obtain the highest-purity inert atmosphere. Vacuum-purged chambers of a large variety of shapes and various degrees of atmosphere have been used extensively in the past. Reliability, consistency of atmosphere purity, and high-obtainable purity have been the main reasons for the widespread use of this type of chamber. However, at times these properties are incorrectly assumed to be characteristics of any vacuum-purged system. The advantages of vacuum-purged chambers can only be sustained by close supervision of their use by personnel familiar with (1) vacuum-system principles, (2) the various components which make up the chamber system, and (3) proper maintenance schedules for the system.

The designer and user of a vacuum-purged chamber must remember that such a system has two functions: (1) as a vacuum system and (2) as a low-pressure system. A complete discussion of vacuum-system principles is beyond the scope of this paper but the brief discussion below will highlight some of the considerations with this design.

The characteristics of vacuum systems which are of interest to the welding engineer are shown in Figure 5. The influence of the pumping system on these characteristics is also indicated. Mechanical pumps are generally used on large systems designed for evacuation to pressures above 25 microns or small systems designed for evacuation to about 1 micron. Diffusion pumps are normally used for systems which are evacuated below 25 microns, and must be used to obtain the best evacuation. Pump down time is of importance because of economics. One method of lowering this time is to keep the

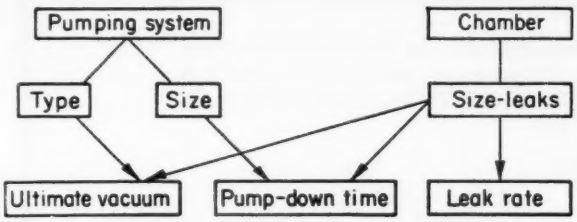


Figure 5. Simplified relation of factors affecting vacuum-system characteristics.

chamber size as small as possible. Chambers which cover only the area to be welded can often be used to achieve this end.

As indicated in Figure 5, both ultimate vacuum and leak rate should be considered in evaluating a chamber system. Large pumps can easily produce and maintain a low pressure in a system with a sizeable leak. Leak rate is a measure of the chamber's ability to hold a vacuum with the pumps stopped. Also of importance is the method and location of measuring the chamber pressure. Vacuum gages that depend on electrical phenomena are most generally used. Such gages are preferred to mercury gages since they indicate the total impurities present, whereas mercury gages are insensitive to condensable vapors.

SUMMARY

Controlled-atmosphere arc welding is becoming increasingly important to the successful welding of materials and products which, until recently, were laboratory curiosities. The choice of atmosphere shielding devices ranges from the simple shielding cups to completely enclosed chamber systems. The welding engineer must carefully consider each welding problem to determine the degree of weld shielding required to produce satisfactory weldments with the required properties. Although vacuum-purged chamber systems undoubtedly offer maximum protection and reliability, any tendency to make their use mandatory for a given material should be carefully scrutinized. Often, a carefully engineered but less sophisticated technique will be adequate.

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ADDENDUM

The author, Mr. Donald L. Herr, has computed data on two recent satellites and additional data on Sputnik III which follows as an addendum to Table B of: "CONIC-SECTION ORBITS DERIVED FROM THE GRAVITATIONAL POTENTIAL" the JOURNAL, November, 1958

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Addendum to
Table B

Satellite or Planet	"m" (pounds)	T (minutes)	$U_{rel.}$, Relative Total Energy, (Vanguard I around Earth, Unit Reference)
S^*_{III}	9919	106	3568 (Earth-Orbiting payload and case)
A_I	8700	95	3368 (Earth-orbiting Atlas payload and case)
Mechta	4041	6.48×10^5 (est.)	19981 (Sun-orbiting payload and container)

Weight of Earth taken as 6.1×10^{27} gms., of Sun as 1.9×10^{33} gms.

S_{III} (earth weight of payload only) was included in the original list.

The versatility of solid state electronic devices continues to be demonstrated in rapid developments. Westinghouse has developed a thermistor, a solid state device which illustrates a remarkably abrupt resistance change at a specified desired temperature. The sudden increase in resistance at a given temperature is equivalent to the action of a thermal switch. The device can thus be used as a contactless protection device against overheating in many circuit applications. When the temperature falls below the critical value, the resistance decreases suddenly and produces the effect of closing a switch.

—from MECHANICAL ENGINEERING
January, 1959

A miniature tape recorder contained in a package 9 inches long, 5 inches high and 4½ inches wide has been developed for missile and satellite application by Lockheed Aircraft Company. Capable of storing three million pieces of scientific information, the recorder weighs 8 pounds and can withstand 50g accelerations. It can record and store data, and on command, read out the data at an accelerated rate. The unit is completely transistorized and requires 10 watts for operation.

—from COMPUTERS AND AUTOMATION
December, 1958

WILLIAM E. MACCOUN

Rear Admiral William E. Maccoun, U.S.C.G. (Retired) passed away in Arnold, Maryland on 30 November, 1958. He was born on September 24, 1871 in Baltimore, Maryland. His father, who served in the Civil War, was a Senior Surgeon in the U.S. Navy. After completion of his apprenticeship in locomotive and ship repair shops as a machinist Admiral Maccoun went to sea as an engineer on merchant vessels. He entered the forerunner of the Coast Guard, the Revenue Cutter Service, as an engineering officer at the age of twenty two. Admiral Maccoun participated in the Spanish-American War under Admiral Dewey at the Battle of Manila Bay. In addition to being awarded prize money for his participation he received the Medal of Honor. Admiral Maccoun served throughout World War I on Coast Guard cutters doing convoy duty between Gibraltar and the British Isles. After World War I he served in various engineering capacities including Inspector for the Emergency Fleet Corp, and Engineer of the Coast Guard Yard at Curtis Bay, Maryland. Upon his retirement in 1935 he was the senior engineering officer of the Coast Guard. Following his retirement he lived in California for a number of years, returning to Maryland in 1957. He is survived by seven children and eighteen grandchildren.

In Admiral Maccoun's death, the Society has lost one of its oldest members in point of service. His membership stems from 1906.

BOOK REVIEWS & NOTICES

NAUTILUS 90 NORTH

by Commander William R. Anderson, U.S. Navy
with Clay Blair, Jr.

Published by The World Publishing Company
2231 West 110th St., Cleveland 2, Ohio
251 pages 58 Illustrations $3.95

We judge that the purpose of this book is to tell a personal story—that of the crew of the *Nautilus* and their outstanding achievement. We consider that this has been well done and that the book is ranged properly with other classical sagas of the sea and of the exploits of those who challenge the sea and ice.

The book tries to keep alive the Rickover "Controversy" which adds nothing either to the book or to that controversy. In the long run it is going to make little difference whether the United States owns the *Nautilus* because of Admiral Rickover in spite of the Navy or because of the Navy's employment of Admiral Rickover to spearhead a tough job.

The *Nautilus* was built. Her builders, her Captain and Crew have established many firsts through and with her. Perhaps the most important of these is described in Commander Anderson's story principally because of the things which he leaves unsaid.

One judges from the first unsuccessful attempt to enter the Arctic Ocean from the Pacific that there is strong probability that the only Pacific access which is open to the free world is only seasonally open—that during many months of the year, this ocean cannot be entered from the Pacific in the narrow and shallow passages between the American and the Russian mainlands. How safe is it to assume that in the long Siberian coastline which borders the Arctic, the Russians do not have or have not or can not make many entrances? What might this mean in regard to the proper development of the coast of Northern Alaska? Commander Anderson has pointed out the great possibility which the Arctic offers as an avenue of commerce and as a launching area for IRBMs fired from submarines. As to the possibility of the area as an arena of combat in the struggle in which we are now engaged, he leaves much to the imagination.

We can assume, from the book that the secrecy which attended the *Nautilus*' polar cruise before it was successfully consummated was not breached *by any means of detection which the United States has in operation.* If this is so, how soon may the Russians be cruising the same waters in easy range of many vulnerable targets *without our knowledge?*

Could the Arctic be of far greater importance to the Free World than outer space is? Certainly it seems that its importance is much more immediate. Does full exploitation of the Arctic both to be able to counter the threat which may come from there and to explore its full potentiality for offensive-defensive operations, beckon as the proper scene of our next great effort. Should this problem be given the same open-purse and overriding priority as permitted the Manhattan Project to succeed? This is not a question of a few men nor of the Navy but of the entire free world.

JANE'S FIGHTING SHIPS

1958-59

Compiled and edited by
Raymond V. B. Blackman, A.M.I.N.A., A.I.Mar.E.

Printed in Great Britain

Distributed in the United States by
The McGraw-Hill Book Co., Inc.
330 West 42nd St., New York 36, N.Y.

This is a book which really needs no review. "Jane's" is well known for its completeness and authenticity and detail which are of such interest and value to the strategist, the tactician, the politician, the statesman, the diplomat, the naval architect, the engineer, the historian, the student that nothing need be said except that the 61st edition is now available and that the standards which were set by the founder, Fred T. Jane, have been maintained by his successors.

Since the format of the 60th edition departed from the "horizontal" which had become so well known as a characteristic of Jane's, to the "vertical," continuation of the 1957-58 format will require no familiarization by the regular patrons of this classic. New readers will find the book a little unwieldy but this would be impossible to avoid without going to multiple volumes or eliminating much material.

Jane's 1958-59 contains descriptive matter of 10,500 ships belonging to the navies of 66 different countries. As usual there is a profusion of photographs and scale drawings, 2500 of which 400 are new, in this edition. The text with tables and illustrations occupy 446 well filled pages.

We would find the table of contents easier to locate and use if it appeared in the front of the book instead of behind the advertising section. We also believe that the conventional location of the index, which in this case is a paged list of the ships described, at the back of the book would be an improvement.

Many important facts can be gleaned from Jane's beyond the mechanical description of ships. These are summarized by the editor and probably are as authentic as it is possible for any print available to the general public to be in these days of conflict and close security of information.

Very strikingly the book supports the known fact that there are only two real centers of power in the world today. Approximate figures of overall Navy personnel strengths are given. For the United States and Russia, there are approximately 800,000 and 750,000 respectively total Navy and Marine personnel. In the same terms the strength of the British Navy which is third in size, is given as 112,000. All of the other 63 navies combined hardly equal Russia by this measure.

Any comparison of navies by numbers or tonnage of ships would of course give the United States an advantage of at least three to one over Russia but the manpower comparison indicates not too wide a separation in the strength of the active fleets. Jane's credits Russia with 32 cruisers, 180 destroyers, 500 submarines, 300 frigate, 1000 minesweepers, 125 patrol vessels, 500 motor torpedo boats, 120 landing crafts and 160 fleet auxiliaries. The really significant things about these numbers are that practically all of them are of post World War II construction and all which are not undergoing refit are fully manned and ready. A large part of the United States' strength in ships is in the reserve fleets in mothballs and only a handful of ships represent design and construction since the War.

It appears that the immense naval shipbuilding programs which Russia undertook after the War and which catapulted her into a strong second position has been reoriented during the last two years. There is evidence, although Jane's does not present the evidence to support the statement, that Russia's building program is being converted to fewer ships of new types and more lethal weapons systems and that she is concentrating on nuclear powered ships.

Aircraft carriers are still the exclusive property of the West. Not a single one is accredited to Russia nor to any of her satellites or allies. In terms of conventional naval warfare, the Russian Navy could be considered as designed to harass and deter surface navies while destroying the merchant navies.

Perhaps a good summary of the world's 1958-59 naval situation is contained in the book in the words:

"In recent months it has become clear that the overall technological lead which the U.S. held over Russia is diminishing. Russia is now a first class naval power, second only to the U.S."

"FUNDAMENTALS OF PIPE DRAFTING"

By Charles H. Thompson

Published in 1958 by
John Wiley & Sons, Inc.
440 Fourth Avenue, New York 16, N.Y.
66 Pages of text and illustrations

Reviewed by
C. M. Wetzel, Supervisory Naval Architect,
Bureau of Ships, Navy Department

Chapter headings:

1. Introduction
2. Piping Symbols
3. Methods of Representing Piping Symbols
4. Diagram Drawing
5. Controls
6. Pipe and Pipe Fittings
7. Specification of Parts
8. General Arrangement and Diagram Drawings
9. Detail Drawing

Appendix "The Language of Piping"

This is an excellent book for the young engineer or draftsman specializing in piping system design. It is well written and illustrated, so that it is useful both for training and information purposes. It shows various methods of delineating piping systems from simple line digrams to detail drawings for illustrating. The limit of detail is left, however, to the policy of the engineering office as the book does not stress modern simplified drawing practices, a consideration for time saving techniques.

General principles of pipe system drafting are presented along with more specific information, such as ASA piping symbols and lists of standard fitting and valve dimensions. A chapter on controls covers the various valve types for controlling piping systems, with illustrations showing details of valves and other piping system components. The chapter on pipe and pipe fittings discusses pipe materials and their application for various temperatures and fluids. Pipe detail work for shop fabrication drawings is covered by appropriate illustrations and text. Pipe drafting problems, valuable for draftsman training, are presented at the end of each chapter.

The author, Mr. Thompson, Head of the Drafting and Design Department, The Technical Institute, College of Engineering, Oklahoma State University, shows a fine understanding of the novice piping draftsman's needs.

The book is written on a specialized subject not usually covered in detail in courses in mechanical drawing. The material is clearly and concisely written and should be valuable to companies and agencies whose work includes considerable or complex piping system designs.

BOOKS RECEIVED

"Cradle of Ships", by Garnett Laidlaw Eskew, published in 1958 by G. P. Putnam's Sons, New York. A history of the Bath Iron Works, 279 pages, $6.00.

"Battleship Scharnhorst", by Albert Vulliez and Jacques Mordal, Translated from the French by George Malcolm, published in 1958 by Essential Books, Fair Lawn, New Jersey: 256 pages, $6.00.

"Nuclear Reactors for Power Generation", edited by E. Openshaw Taylor, published by Philosophical Library, Inc., 15 East 40th Street, New York 16, New York: 144 pages, $7.50.

"A Handbook on Torsional Vibration", compiled by E. J. Nestorides of the British Internal Combustion Engine Research Association; published in 1958 by the Cambridge University Press, 32 East 57th Street, New York 22, N. Y. (American Branch): 664 pages, $19.50.

"The Atom and The Energy Revolution", by Norman Lansdell, published in 1958 by Philosophical Library, Inc., 15 East 40th Street, New York 16, New York: 200 pages, $6.00.

CHANGES IN MEMBERSHIP

ADDITIONS TO MEMBERSHIP

The Society announces with pleasure that the following have joined its ranks since the publication of the November 1958 issue of the JOURNAL.

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McFadden, Charles F., LTJG, USCG

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Holtz, E. W., Capt., USCG, Naval
Humphreys, William T., Associate
Johnson, M. R., Associate
Jones, Herbert S., Capt., USN (Ret.), Naval
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Woyciehowsky, S. J., Capt., USCG (Ret.), Naval
Zelov, Randolph D., LCDR, Naval

In accordance with the new By-Laws, it is with much regret that we announce the necessity of dropping 154 Regular members and 27 Juniors from our rolls on 31 December 1958 because of arrearage of at least one year in dues.

DEATHS

Billich, W. H. Civil
Bradshaw, George B. Civil
Butterfield, A. M. Civil
Colley, W. E. . . . . Associate
Kingsbury, Jesse A. Civil
Salzer, Harry S., CDR, USCG . . . . . Naval
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Trumpy, Donald Civil
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ASSOCIATION NOTES

ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $50.00 to $250.00 depending upon length, interest and professional value. Payment is made at time of acceptance.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. *Include on a separate page a short biographical sketch(es) of the author(s).* 50 to 100 words for each author is desired.

Manuscripts should be addressed to:

Secretary-Treasurer
American Society of Naval Engineers, Inc.
1012 14th St., N.W.
Washington 5, D.C.

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